SPECIAL REPORT 99-13

US Army Corps of Engineers®
Cold Regions Research & Engineering Laboratory

# Eagle River Flats Remediation Project

## Comprehensive Bibliography—1950 to 1998

Sae-Im Nam, Michael R. Walsh, Charles M. Collins, and Lisa Thomas

August 1999

**Abstract:** White phosphorus (WP) has been implicated in the deaths of thousands of waterfowl annually at Eagle River Flats (ERF), an estuarine salt marsh located on Fort Richardson near Anchorage, Alaska. The source of WP contamination at ERF was the firing of WP-containing munitions into the area by the U.S. military. WP is a well-known toxicant and is lethal to a wide range of species. However, WP contamination at ERF is the first documented case of a U.S. Army munitions impact area contaminated with WP particles. This has led to the designation of ERF as a Superfund site by the U.S. Environmental Protection Agency, and the Army must follow the guidelines of remediation set by the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA). Numerous studies have been conducted to better characterize the nature and the extent of WP contamination, and treatability studies for remediation processes are currently being implemented. This comprehensive bibliography provides all publications related to WP contamination remediation project at Eagle River Flats through 1998.

**How to get copies of CRREL technical publications:**

Department of Defense personnel and contractors may order reports through the Defense Technical Information Center:

DTIC-BR SUITE 0944
8725 JOHN J KINGMAN RD
FT BELVOIR VA 22060-6218
Telephone 1 800 225 3842
E-mail help@dtic.mil
msorders@dtic.mil
WWW http://www.dtic.mil/

All others may order reports through the National Technical Information Service:

NTIS
5285 PORT ROYAL RD
SPRINGFIELD VA 22161
Telephone 1 703 487 4650
1 703 487 4639 (TDD for the hearing-impaired)
E-mail orders@ntis.fedworld.gov
WWW http://www.ntis.gov/index.html

A complete list of all CRREL technical publications is available from

USACRREL (CEERD-IM-HT-HL)
72 LYME RD
HANOVER NH 03755-1290
Telephone 1 603 646 4338
E-mail techpubs@crrel.usace.army.mil

**For information on all aspects of the Cold Regions Research and Engineering Laboratory, visit our World Wide Web site:**

**http://www.crrel.usace.army.mil**

Special Report 99-13

US Army Corps of Engineers®
Cold Regions Research & Engineering Laboratory

# Eagle River Flats Remediation Project
## Comprehensive Bibliography—1950 to 1998

Sae-Im Nam, Michael R. Walsh, Charles M. Collins, and Lisa Thomas

August 1999

Prepared for
U.S. ARMY ENVIRONMENTAL CENTER

## PREFACE

This report was prepared by Dr. Sae-Im Nam, Toxicologist, Hanover, New Hampshire, Michael R. Walsh, Mechanical Engineer, Engineering Resources Division, Charles M. Collins, Research Physical Scientist, Geological Sciences Division, U.S. Army Cold Regions Research and Engineering Laboratory, and Lisa Thomas, a CRREL summer intern from Oregon State University. Technical Review of the manuscript was provided by Dr. Charles H. Racine, Research Biologist, Geological Sciences Division, CRREL, and John Cummings, Research Wildlife Biologist, Animal and Plant Health Inspection Service, U.S. Department of Agriculture. Mark J. Hardenberg of CRREL was the editor.

Every attempt has been made to bring this bibliography up to date and to include all materials relevant to the project that have been published. If any articles are known that have not been included, contact Michael Walsh at CRREL and they will be added to the next revision of this bibliography. Any items added to the bibliography before the next publication of the Eagle River Flats bibliography will be placed on the public CRREL web site (www.crrel.usace.army.mil/) as we receive them.

Funding for this work was provided by the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland (Karen Wilson, Program Manager), through the Alaska District, Pacific Ocean Division, U.S. Army Corps of Engineers (JoAnn Walls, Project Monitor), and the Environmental Resources Department, Directorate of Public Works, U.S. Army Alaska (William A. Gossweiler, Army Remedial Project Manager).

## CONTENTS



## ILLUSTRATIONS

## NOMENCLATURE

| | |
|---|---|
| ADC | Animal Damage Control |
| ADEC | Alaska Department of Environmental Conservation |
| ADFG | Alaska Department of Fish and Game |
| APHIS | Animal and Plant Inspection Service |
| ARAR | Applicable or relevant and appropriate requirement |
| BT Pond | Bread Truck Pond |
| CER | Comprehensive Evaluation Report |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| COE | U.S. Army Corps of Engineers |
| CSM | Conceptual site model |
| DMS | Dartmouth Medical School |
| DMSV | Digital multispectral video |
| DOD | Department of Defense |
| DQO | Data quality objectives |
| DWRC | Denver Wildlife Research Center |
| EOD | Explosive ordnance disposal |
| ERF | Eagle River Flats |
| ESE | Environmental Science and Engineering, Inc. |
| FFA | Federal Facilities Agreement |
| FS | Feasibility Study |
| FSP | Field Sampling Plan |
| GIS | Geographic information system |
| IRA | Interim remedial actions |
| IRAM | Integrated risk assessment model |
| IRP | Installation Restoration Program |
| $LD_{50}$ | Median lethal dose |
| LOEL | Lowest observable effects level |
| MA | Methyl anthranilate |
| MDL | Method detection limits |
| MOA | Municipality of Anchorage |
| NBS | National Biological Survey |
| NCP | National Contingency Plan |
| NEILE | New England Institute of Landscape Ecology |
| NOEL | No observable effect level |
| NPL | National Priorities List |
| OB/OD | Open Burning/Open Detonation |
| OUC | Operable Unit C of Fort Richardson |
| QA | Quality assurance |
| QAPP | Quality Assurance Program Plan |
| QC | Quality control |
| RAO | Remedial action objectives |
| RCRA | Resource Conservation and Recovery Act |
| RI | Remedial Investigation, Racine Island |
| ROD | Record of Decision |
| SPMA | Semi-permeable membranes |
| SPME | Solid phase microextraction |
| TSCA ITC | Toxic Substance Control Act Interagency Testing Committee |
| USAEC | U.S. Army Environmental Center |
| USAEHA | U.S. Army Environmental Hygiene Agency |
| USARAK | U.S. Army Alaska |
| USATHAMA | U.S. Army Toxic and Hazardous Materials Agency |
| USDA | U.S. Department of Agriculture |
| USEPA | U.S. Environmental Protection Agency |
| USFWS | U.S. Fish and Wildlife Service |
| UXO | Unexploded ordnance |
| WP | White phosphorus |

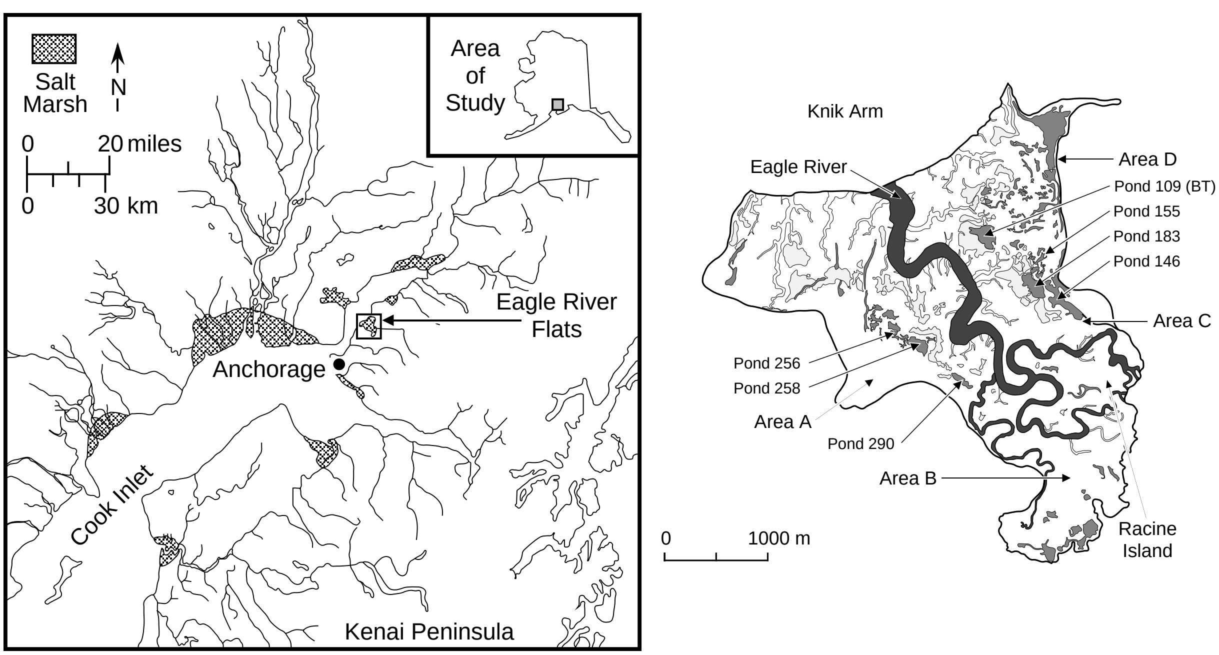
# Eagle River Flats Remediation Project
## Comprehensive Bibliography—1950 to 1998

SAE-IM NAM, MICHAEL R. WALSH, CHARLES M. COLLINS, AND LISA THOMAS

### INTRODUCTION

Eagle River Flats (ERF) is an estuarine salt marsh located at the mouth of Eagle River, along the upper Cook Inlet, near Anchorage, Alaska (Fig. 1). This 865-ha region, which is within the Fort Richardson Army Base, serves as a staging area for the migrating waterfowl population during the spring and fall migration season. ERF has also been used by the U.S. Army as its primary munitions impact area for Fort Richardson since the late 1940s.

High waterfowl mortalities at ERF were first noted in the early 1980s. An increased number of carcasses, as well as feather piles along the edge of the salt marsh, were the first indications that more deaths were occurring than in previous years. The species of birds that suffered the most mortalities were the dabbling ducks and swans. The cause of deaths could not be readily explained, and, in 1982, various government agencies (U.S. Fish and Wildlife Service, the Alaskan Department of Fish and Game, and the U.S. Army Directorate of Environmental Hygiene) joined efforts to further examine this problem. Eventually, an Eagle River Flats Interagency Task Force was established with members from the U.S. Army, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the Alaska Department of Fish and Game, the Alaska Department




*a. Location of ERF.* *b. Closeup.*

*Figure 1. Anchorage, Alaska, area showing the location of ERF.*

of Environmental Conservation, and the U.S. Army Toxic and Hazardous Materials Agency, now known as the U.S. Army Environment Center.

### Initial investigations

During the years 1983 through 1988, samples of water, sediment, and animal tissues from ERF were collected and analyzed. The water and sediment samples were analyzed by the Army Environment Hygiene Agency, the Alaska Department of Environmental Conservation, the Environmental Protection Agency, and Environmental Science and Engineering, Inc. The water and sediment analyses did not show any major contaminants that could have led to waterfowl deaths. Bird carcasses collected at ERF were given detailed necropsy and tissue analyses by the U.S. Fish and Wildlife Service, the National Wildlife Health Research Center, and the Patuxent National Wildlife Research Center in conjunction with the University of Missouri Environmental Trace Substance Research Center. Their findings ruled out poisoning of the birds by pesticides or metals, or infection by bacteria or viruses. The gastrointestinal contents of some of the birds collected at ERF in 1983 had what were considered to be abnormally high levels of total phosphorus. However, in 1984, total phosphorus levels in the gastrointestinal contents of birds collected at ERF were not drastically different from those at a control site. These findings were considered inconclusive.

During the course of this investigation, CRREL had become involved owing to our expertise in munitions analyses. Since ERF was used as an artillery training area, components of various munitions were being further investigated. In 1990, scientists from CRREL began collecting samples and making detailed observations of where the birds were dying and of characteristic signs of poisoning. Analyses of sediment and water samples resulted in identification of two chemicals that are components of munitions used by the U.S. Army. The first compound, 2,4-dinitrotoluene (2,4-DNT), is one of the compounds in the M1 mixture that is the major component of a propellant; the other compound, white phosphorus (WP), is used in smoke rounds. More extensive analyses and laboratory experiments ruled out 2,4-DNT, but implicated WP as the cause. CRREL and Dartmouth College scientists observed that laboratory ducks dosed with WP showed similar signs of intoxication as the sick ducks at ERF. Further, CRREL found WP in the tissues of birds collected at ERF and in the sediments of shallow ponds that were frequently used by waterfowl.

Contamination by munitions at ERF is not at all surprising, since the area has been used for artillery training for many years; however, the persistence of WP in the environment was not expected. Because of the reactive nature of WP with oxygen, earlier studies predicted that WP would readily oxidize in air and that very little of the original form would be deposited into the terrestrial or aquatic environment. However, findings by CRREL showed that the environmental conditions at ERF, including low redox potentials of the sediments and frequent deposition of sediment by flooding, all contributed to WP stability. Therefore, the dabbling ducks foraging for food in ponds at ERF would most likely be ingesting WP particles as well as their normal diet of seeds and invertebrates (Fig. 2).

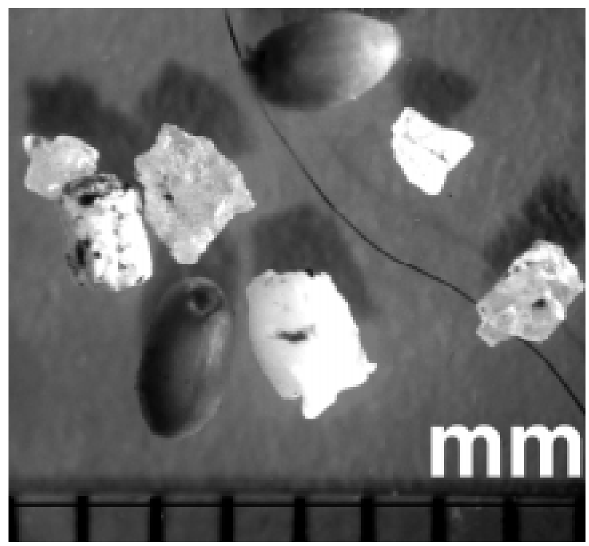



*Figure 2. White phosphorus particles and seeds retrieved from Eagle River Flats.*

### Site and contaminant investigations

During the 1991–1994 seasons, numerous agencies worked together to conduct studies that would further characterize the site and to better understand the fate and transport mechanism of WP. Remedial alternatives were also evaluated during this time. The physical characterization of ERF, such as identifying habitat and vegetation, climate and tides, and physical system dynamics (erosion and sedimentation rates), was done by CRREL. The contamination profile of WP and other contaminants in sediment and water samples was created by the U.S. Army Environmental Hygiene Agency (USAEHA), while CRREL determined the distribution and concentration of WP in sediment and water samples in detail and conducted a literature review of the chemical and physical properties of WP.

Biological and toxicological studies, which were mostly conducted by the U.S. Fish and Wildlife Service (USFWS) and Dartmouth Medical School (DMS), primarily focused on characterizing WP toxicity in mallards. Researchers from USFWS and DMS conducted experiments to determine the lethal dose of WP to mallards, the distribution of WP in tissues of ducks poisoned with WP, the risk of secondary poisoning to predators of ducks, the identification of biomarkers in birds poisoned with WP, reproductive toxicity, the feasibility of treating WP-poisoned birds, preliminary theories on the mechanism of toxicity, and WP concentrations in tissues of bird, invertebrate, and fish samples collected at ERF. Plant samples were also collected and analyzed for WP by CRREL. Waterfowl surveys, which included utilization of ERF, mortality rate, and distribution and movements, were conducted by USFWS, the New England Institute of Landscape Ecology (NEILE), and the U.S. Department of Agriculture (USDA), respectively.

**Remedial investigations and feasibility studies**

Several remedial methods were also evaluated from 1991–94. Waterfowl deterrent methods—such as hazing, exposure to methyl athranilate, and covering of contaminated areas with Concover, AquaBlok™, and BentoBalls®—were investigated by the USDA. CRREL also studied using various geosynthetic coverings for the contaminated areas, as well as looked at methods to dry sediments in situ and drain ponds. Finally, CRREL developed a database for ERF, using a Geological Information System (GIS), to maintain and update incoming data.

Studies conducted during 1995–98 mostly focused on active remediation and monitoring its effects. In 1995, treatability studies, such as pond draining by explosive ditching, dredging, and the enhancement of natural attenuation processes, were conducted to determine how effective these treatments are in reducing WP availability. Hazing and AquaBlok™ coverage were also evaluated for their effectiveness in breaking the contaminant pathway. Waterfowl surveys were continued to monitor the mortality, movement, and distribution of migrating birds.

In 1996 and 1997, studies were again geared towards treatment of contaminated areas to reduce WP availability. Dredging and draining of ponds, both through explosive ditching and pumping, seem to be effective in reducing WP concentration. Especially promising is the pond pumping remediation method, which removes overlying water from contaminated sediments. First tried on a limited scale in 1997 as part of the feasibility study, pumping reduced contamination in a large, highly contaminated pond by over 80% during one summer. Dredging was dropped from consideration following this test, and six pumps were deployed in 1998 with similar results.

**Regulatory actions**

In June 1994, ERF was placed on the National Priorities List (NPL) by the U.S. Environmental Protection Agency (USEPA). Designated as Operable Unit C (OUC), ERF became a Federal Superfund site, which mandates that the area be subject to the remedial response requirements of the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), as amended by the *Superfund Amendments and Reauthorization Act* of 1986. Prior to the actual placement of ERF on the NPL, the U.S. Army Engineer District, Alaska, hired a private consulting firm, CH2M Hill, to review all previous studies and to aid in organizing an effective and coordinated CERCLA remedial activity. In 1994, CH2M Hill, working in conjunction with the agencies involved in the ERF investigation, produced the *Comprehensive Evaluation Report* (CER), which reviewed all work that had been done through 1994. Quality assurance (QA) plans (1994), as well as field working plans (1995), following the CERCLA guidelines were also written. In 1997, the final draft of *Operable Unit C, Final Feasibility Study Report* and *Operable Unit C, Remedial Investigation Report* became available. The final risk assessment report became incorporated in the *Operable Unit C, Remedial Investigation Report*. The CERCLA documents, *Proposed plan for cleanup action at Operable Unit C* and the *Record of Decision for Operable Unit C*, are now also available to the public.

With the signing of the Record of Decision (ROD) in October 1998, full-scale remediation of Eagle River Flats will begin. The preferred remediation method is pond pumping, with the application of AquaBlok™ in areas that pumping cannot address. Effectiveness will be measured in two ways. Baseline sampling for the contaminant will be carried out in untreated ponds and ponds in the process of being treated in the spring. In the fall, the treated ponds will once again be sampled to determine the reduction in white phosphorus contamination. Waterfowl mortality will be monitored using radio-collared wild mallard ducks, previously captured at ERF. Goals and endpoints are to be measured as a mortality percentage of the radio-collared mallards. The 5-year goal (2003) is a 50% reduction in mortality, based on 1996 mortality data, and the 20-year goal is a reduction in mortality to 1% of the total population.

**Objective**

The purpose of this report is to provide a thorough and complete list of publications on the subject of WP contamination and remediation at Eagle River Flats, Alaska. To date, there are about 250 references in the ERF Bibliography, including CERCLA documents, conference papers, contract reports (encompassing many individual reports), journal articles, aerial photos or photographic series of ERF, newspaper and magazine articles, patents, reports, theses, videotapes, and web sites. An index is provided at the end of this report for those documents with abstracts included.

---

## AERIAL PHOTOGRAPHS OF ERF

(1950) 8 August. Greyscale. 1 in. = 1500 ft.
(1953) 27 June. Greyscale. High altitude.
(1957) 12 June. Greyscale.
(1960) 30 August. Greyscale. 1:60,000.
(1962) 17 May. Greyscale. 1:6000.
(1967) Greyscale.
(1972) 9 August. Greyscale.
(1972) July. Color infrared.
(1974) 7 May. Greyscale. 1 in. = 1000 ft.
(1977)
(1978) August.
(1984) 12 August. Color infrared. High altitude.
(1984) 2 September. True color. 1 in. = 1000 ft.
(1986) 5 October. True color. 1 in. = 1000 ft.
(1986) 12 September. Landsat TM.
(1988) 4 August. Greyscale. 1 in. = 3000 ft.
**Aeromap** (1990) 24 May. True color. 1:21,000.
**Aeromap** (1991) 21 June. CASI. 2.5-m pixels.
**Aeromap** (1991) 21 June. Color infrared. 1 in. = 600 ft.
**Aeromap** (1992) 2 August. Color infrared. 1 in. = 1000 ft.
**Aeromap** (1992) 22 May. Color infrared. 1 in. = 500 ft.
**Aeromap** (1993) 8 July. Color infrared.
**Aeromap** (1993) 8 July. Greyscale orthophoto.
**Aeromap** (1994) 30 August. Color infrared. 1 in. = 600 ft.
**Aeromap** (1994) 30 August. Digital orthophoto.
**Aeromap** (1995) 11 August. Digital multi-spectral video. 1.5-m pixels.
**Aeromap** (1995) 16 August. Color infrared. 1 in. = 600 ft.
**Aeromap** (1995) 9 October. True color. 1 in. = 1200 ft.
**Aeromap** (1996) 4 October. True color. 1 in. = 500 ft.
**Aeromap** (1997) 14 August. Greyscale. 1 in. = 2500 ft.
**Aeromap** (1997) 27 July 1997. True color. 1 in. = 500 ft.
**Aeromap** (1997) 11 June. Digital multi-spectral video. 1.5-m pixels.
**Aeromap** (1997) 17 June. Digital multi-spectral video. 1.5-m pixels.
**Aeromap** (1997) 24 May. True color. 1 in. = 1000 ft.
**Aeromap** (1998) 18 August. Color infrared. 1 in. = 600 ft.

**CH2M Hill** (1994) Eagle River Flats. Comprehensive Evaluation Report. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. July.

*Scope and purpose of the comprehensive evaluation report*

The U.S. Army Corps of Engineers (COE), Alaska District, on behalf of the U.S. Army Garrison at Fort Richardson, Alaska, has contracted with an independent engineering consulting firm to complete a Comprehensive Evaluation Report (CER) for the Eagle River Flats (ERF) area on Fort Richardson. In 1993, Fort Richardson was proposed for inclusion on the National Priorities List (NPL). The NPL is administered by the U.S. *Environmental Response, Compensation, and Liability Act* (CERCLA). The purpose of the NPL is to inform the public of the most seriously contaminated sites in the nation, through site-specific criteria and a preliminary evaluation of potential contamination that may pose a substantial risk to human health or the environment.

CERCLA requires that Federal facilities investigate and clean up contaminated sites according to specific interagency agreements. The U.S. Army is currently negotiating a Federal Facility Agreement (FFA) with USEPA and the Alaskan Department of Environmental Conservation (ADEC) for Fort Richardson. The purpose of the FFA is to ensure that environmental impacts associated with a site are thoroughly investigated and remediated. Work at a Department of Defense NPL site that is carried out under the Installation Restoration Program (IRP) is planned and completed as required by CERCLA according to the terms specified in the FFA.

The ERF site of Fort Richardson is one area that has been investigated under the IRP and is included in the upcoming FFA. The CER is the result of a review and evaluation of the various studies and investigations completed at the ERF since 1982. The CER summarizes and presents the information obtained to date from the ERF investigations. It is designed to assist the U.S. Army and the signatories to the FFA in determining practical, implementable, and effective remedial actions for the ERF.

The CER includes the following:

- Description of the general site location and environmental setting of the ERF (Section 2).
- Summary of past studies and investigations, including the results and identification of chemicals of concern (Section 3).
- Conceptual site model (CSM) that describes the fate and transport of contaminants and identifies potential data gaps from past studies (Section 4).
- Qualitative assessment of potential risks posed to human health and the environment from the contamination at the site (Section 5).
- Criteria for evaluating treatability studies developed by the USEPA (Section 6).
- Data quality objectives (DQOs) that describe the type, quantity, and quality of existing data and present additional data that may be necessary for evaluating risk, conducting treatability studies, determining cleanup goals and objectives, and completing remedial design (Section 7).

Applicable or relevant and appropriate requirements (ARARs) that must be met during field activities and at the conclusion of remediation are discussed in a separate document. The information presented in the CER will be used to design and implement potential interim remedial actions (IRAs), removals, and treatability studies for the successful remediation of any contamination at the ERF that poses a substantial risk to human health and the environment.

*Background*

The ERF is an estuarine salt marsh in the northwest sector of Fort Richardson. Fort Richardson's 55,000 acres include a central cantonment area surrounded by ranges and impact and maneuver areas to the north, east, and south. The Municipality of Anchorage (MOA) and Elmendorf Air Force Base (AFB) lie west of Fort Richardson.

The ERF has been as the primary ordnance impact area for Fort Richardson since the mid-1940s. The ERF is a 2165-acre wetland within Fort Richardson at the mouth of Eagle River, adjacent to Upper Cook Inlet. The ERF is an important staging ground for several species of waterfowl, including ducks, geese, and swans, during spring and fall migrations. During the peak migration periods, the waterfowl population may total 3000 to 5000.

A former explosive ordnance disposal (EOD) pad, where outdated munitions were detonated, adjoins the eastern boundary of the ERF. Ordnance fired into the ERF since 1949 includes machine gun and rifle rounds, grenades, rockets, and incendiary missiles. Various calibers of artillery rounds fired into the ERF include smoke obscurants (smokes), illumination flares, and high-explosive rounds.

In 1980, U.S. Army biologists first noticed an unusually high number of waterfowl carcasses, including several dead swans, in the ERF marshes. Between 1982 and 1985, random ground searches were conducted at the ERF by the U.S. Army, the U.S. Fish and Wildlife Service (USFWS), and the Alaskan Department of Fish and Game (ADFG). The discovery of abnormally high numbers of dead waterfowl during the searches indicated that a potentially serious problem existed. The dead and dying waterfowl were looked for and observed in several areas, including those referred to as Areas A, B, C, and D.

To approach the problem in an organized and scientific manner, an interagency task force was formed in 1987. The ERF Task Force was composed of representatives from the following Federal and state agencies:

- U.S. Army.
- USEPA.
- USFWS.
- ADFG.
- ADEC.

The primary objective of the ERF Task Force was to identify the cause of the waterfowl die-offs and recommend remedial alternatives. Since the formation of the ERF Task Force, several studies and investigations have been conducted to identify contaminants of concern, to characterize the nature and extent of contamination, and to evaluate potential remedial alternatives.

In addition to the ERF Task Force member agencies, other agencies and consultants that have been involved in the investigations at the ERF include the following:

- COE, Alaska District.
- U.S. Army Cold Regions Research and Engineering Laboratory (CRREL).
- U.S. Army Environmental Hygiene Agency (USAEHA).
- U.S. Army Environmental Center (USAEC) (formerly U.S. Army Toxic and Hazardous Materials Agency [USATHAMA]).
- U.S. Department of Agriculture (USDA).
- Environmental Science and Engineering, Inc. (ESE).

The results of a 1989 study by ESE under contract to USATHAMA indicated that chemicals from explosives ordnance were the probable cause for the waterfowl mortality at the ERF. Field and laboratory studies conducted by CRREL between 1990 and 1992 provided evidence that white phosphorus (WP), used in smoke obscurants, was the likely cause of the mortality.

In February 1990, on the basis of the conclusions of the ESE report, the Army temporarily suspended the use of the ERF for live firing until the causative agent of waterfowl mortality was identified. The 1990 CRREL report identified the causative agent to be WP. With this conclusion, the Army initiated a public review process that evaluated alternatives for the resumption of live firing. The ERF was reopened for firing uses in January 1992, following a series of test firing, under the following conditions:

- No WP munitions may be used.
- Only point contact detonators may be used.
- A minimum of 6 in. of ice must cover the ERF before it can be used for firing.
- Firing is allowed only between November 1 and March 31.

**CH2M Hill** (1994) Eagle River Flats. Potential ARARs Evaluation. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. July.

Fort Richardson is an active U.S. Army installation near Anchorage, Alaska. Fort Richardson's 55,000 acres include a central cantonment area surrounded by ranges and impact and maneuver areas to the north, east, and south. The Municipality of Anchorage and Elmendorf Air Force Base lie west of Fort Richardson.

On 18 June 1993, Fort Richardson was proposed for inclusion on the National Priorities List (NPL). The NPL is administered by the U.S. Environmental Protection Agency (USEPA) and is used by them to prioritize contaminated sites across the nation that require action under the Federal *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA).

The U.S. Army at Fort Richardson is currently negotiating a Federal Facility Agreement (FFA) with USEPA and the Alaska Department of Environmental Conservation (ADEC). The FFA will establish the framework for developing and implementing appropriate response actions at Fort Richardson in accordance with CERCLA, the National Contingency Plan (NCP), and Superfund guidance and policy. Work that will be done at Fort Richardson, as a Department of Defense (DOD) NPL site, and that is carried out under the DOD Installation Restoration Program (IRP), will be planned and completed as required by CERCLA according to the term specific in the FFA.

The Eagle River Flats (ERF) area of Fort Richardson has been investigated over the past several years for suspected contamination of hazardous substances from past practices and will be included in the upcoming FFA. The ERF has been used as the primary ordnance impact area for Fort Richardson since the middle to late 1940s. It is also an extremely productive wetland area and serves as an important staging and feeding ground for waterfowl during spring and fall migrations. Eagle River, which winds through the ERF area, maintains spawning runs of chinook, coho, and pink salmon. Past investigations at the ERF have focused on identifying the cause or causes of abnormally high waterfowl deaths, including those of at least 10 swans, that have been observed in the ERF area since 1982.

In preparation for future additional CERCLA investigations and potential remedial activities to be conducted at the ERF, the U.S. Army Corps of Engineers, on behalf of the U.S. Army, is preparing a Comprehensive Evaluation Report (CER) that will summarize and evaluate the existing information obtained from various studies and investigations at the site. A discussion of potential applicable or relevant and appropriate requirements (ARARs) is presented in this document to assist decision makers in planning for future feasibility studies, remedial design, and remedial action for the ERF.

**CH2M Hill** (1994) Eagle River Flats. Quality Assurance Program Plan. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. August.

*Authority*

The U.S. Army Corps of Engineers (COE), Alaska District, on behalf of the U.S. Army Garrison at Fort Richardson, Alaska, has contracted with an independent engineering consulting firm, CH2M Hill, to provide a Quality Assurance Program Plan (QAPP) to apply to the field work being performed at the Eagle River Flats (ERF) during 1994.

In 1993, Fort Richardson was proposed for inclusion on the National Priorities List (NPL). The NPL is administered by the U.S. Environmental Protection Agency (USEPA) and is used by the USEPA to prioritize contaminated sites across the nation that require action under the Federal *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA).

CERCLA requires that Federal facilities investigate and clean up contaminated sites according to specific interagency agreements. The U.S. Army is currently negotiating a Federal Facility Agreement (FFA) with USEPA and the Alaskan Department of Environmental Conservation (ADEC) for Fort Richardson. The purpose of the FFA is to ensure that environmental impacts associated with a site are thoroughly investigated and remediated. Work at a Department of Defense NPL site that is carried out under the Installation Restoration Program (IRP) is planned and completed as required by CERCLA according to the terms specified in the FFA.

The ERF site of Fort Richardson is one area that has been investigated under the IRP and is included in the upcoming FFA. A QAPP is typically required for environmental sampling and analysis programs conducted under CERCLA or the *Resource Conservation and Recovery Act* (RCRA). Individual projects may have a specific Quality Assurance Project Plan (QAPP) that accompanies a project-specific field sampling plan (FSP).

*Scope and organization of ERF field QAPP*

During 1994, a number of investigations will be conducted at ERF by CRREL and its subcontracted agencies. This QAPP describes the planned objectives of the 1994 field investigations, the data required to meet these objectives, and the procedures that will be followed to obtain the data. The QAPP may detail sampling locations, sampling procedures, and analytical methods or, where appropriate, will reference specific FSPs (scopes of work) or standard operating procedures. Procedures to review the quality of the data and assess whether they meet the project objectives are also included in the QAPP.

*Limitations*

This field QAPP details procedures and issues relating only to the fieldwork at the ERF, including the collection of all types of measurement data, the field laboratory analyses conducted at the ERF and Fort Richardson, and the handling and shipping of samples to off-site laboratories. The field QAPP is designed to be flexible so that participating agencies can continue to use their standard field forms and operating procedures as long as the basic information and an adequate level of documentation are provided.

This field QAPP does not cover analytical or research activities at off-site laboratories. Once the samples reach the off-site laboratories, laboratory or research agency quality assurance (QA) programs and procedure take over and are cited only by reference in this field QAPP.

*Organization*

This QAPP is consistent with the USEPA guidance document *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*, QAMS-005–80m dated 29 December 1980. The quality control (QC) procedures implemented in the field are discussed to describe how data of known and accepted quality are produced at ERF.

This document consists of the following volumes:

- Volume 1—QAPP and supporting appendices.
- Volume 2—Scopes of work for specific investigations at ERF in 1994.

Volume 1, the QAPP, contains the following sections:

- Program description.
- Program organization and responsibility.
- Quality assurance objectives for measurement of data.
- Sampling procedures.
- Sample custody procedures.
- Calibration and maintenance of equipment.
- Analytical methods.
- Data reduction, validation, and reporting.
- Internal QC checks and frequency.
- Performance and system audits.
- Preventive maintenance procedures and schedules.
- Precision, accuracy, and completeness assessment.
- Corrective action.
- Quality assurance reports to management.

The scopes of work in Volume 2 were written by participating research agencies for each ERF investigation. Each scope of work provides the following:

- Background information.
- Specific objectives.
- Field sampling and analysis plan.
- Quality assurance project plan.
- Health and safety plan.
- Personnel responsibilities.
- Schedules.

*Synopsis of 1994 planned investigations*

The 1994 investigations have the following objectives:

- Develop an integrated risk assessment model.
- Determine effective remedial alternatives that will prevent the waterfowl and secondary receptors from ingesting WP.

The integrated risk assessment model (IRAM) is the joint effort of four research agencies to combine into one model the available information on habitat, waterfowl behavior, WP distribution at the ERF, physical processes (tides, sedimentation, natural attenuation), and WP toxicity. The 1994 summer effort will obtain data to fill in remaining data gaps and then answer the following questions:

- What is the probability of waterfowl encountering and retaining a WP particle?
- Given a probability of encountering particles, what is the probability for toxicosis?

Remedial methods under investigation in 1994 include using waterfowl deterrents (hazing, methyl anthranilate), capping pond sediments (BentoBalls, geotextile liners), dredging and drying sediments, draining the pond and exposing sediments to air, and natural attenuation.

The report summarizes the 1994 projects, including specific objectives, types of measurement data that will be collected, and how the data will be used. The data can be grouped into one of the four data categories: biological, chemical, physical, and meteorological.

Field and laboratory investigations, surveys, and treatability studies will be conducted beginning in March 1994 and continued through October 1994. Data entry and evaluation activities will continue past 1994. On overall ERF 1994 field season schedule produced by CRREL is included.

The research agencies involved in conducting the 1994 fieldwork are as follows:

- CRREL, Hanover, New Hampshire.
- U.S. Army Environmental Hygiene Agency (USAEHA), Aberdeen Proving Ground, Maryland.
- Dartmouth Medical School, Hanover, New Hampshire.
- Denver Wildlife Research Center (DWRC) and Animal Damage Control (ADC), United States Department of Agriculture, Denver, Colorado.
- National Biological Survey (NBS), Patuxent Wildlife Research Center, Laurel, Maryland.
- New England Institute for Landscape Ecology (NEILE), Canaan, New Hampshire.

The data use end points are critical to determining the levels of QA/QC required in gathering the data. Data used for screening information may require less attention to sampling details and lower precision, accuracy, and completeness than data collected to determine toxicity and cleanup levels. Examples of screening-level data include the following:

- Presence or absence of WP.
- Nonparametric observations such as foraging behavior.
- Field measurements (for example, pH, salinity, temperature).

**CH2M Hill** (1995) Eagle River Flats. Final 1995 Work Plan. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. June.

*Project objectives*

During the past 10 years, considerable data have been collected at the ERF. In the early years, the objective was to collect data that could help identify the cause or causes of the acute waterfowl mortality observed at the ERF. With the identification of WP as the causative agent, the focus of the studies shifted to understanding how WP moves and is lost in the wetland environment, as well as studying the toxicology to discover the mechanism of action and the dose–response relationship. A few studies began to investigate potential remedial measures.

With the inclusion of Fort Richardson on the National Priorities List (NPL) and its designation as a contaminated site under the Federal *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), the emphasis at the ERF has shifted to site remediation and compilation of the data needed to support site remedial decisions. Two key decisions for site remediation are the identification of areas that need remediation and the choice of remedial actions to achieve the remedial action goals.

The following are study objectives in 1995:

- Identify data gaps that need to be filled to support the key CERCLA decisions.
- Execute the field and pilot studies that will fill those gaps.

*Scope of work*

The process by which the data gaps were identified is described below. An overview of each study planned for 1995 is provided. These studies are intended to fill the data gaps identified. Specific 1995 project scopes of work can be found.

In 1994, the Eagle River Flats Comprehensive Evaluation Report (CER) summarized the studies performed before 1994; presented a conceptual site model, preliminary human health and environmental risk assessments, and discussion of potential remedial technologies; and described the data needed for key decisions of the CERCLA process. It was used to guide planning for the 1994 field season.

In 1995, the data review consisted of the following steps:

- Review existing data. The data review included the data summarized in the CER and the data presented in the preliminary reports prepared by researchers involved in the 1994 field and laboratory work.
- Determine site decisions. The evaluation focused on the supporting data necessary to determine which areas require remediation and which remediation methods are appropriate for consideration.
- Develop evaluation matrices. Three matrices and criteria were developed to assess data gaps. Further details are provided below.
- Evaluate data needs and availability. The existing information was evaluated in the context of the matrices, and criteria were developed in the previous step. Further details are discussed below.

The results of the risk assessment, which are supported by the conceptual site model (CSM), have the greatest influence on determination of areas requiring remediation. The information categories for these assessments are the nature and extent of contamination (contaminant characterization), the fate and transport processes that govern the contaminants in the ERF, and potential exposure and effects of receptors. These categories were further divided for the analysis of data gaps. The availability of information was considered for several different geographical areas of the ERF, particularly areas that have been assessed in the past. The results are summarized.

In general, the critical data gaps are those cells in the matrix where the impact is *High*, and the confidence is *Low*. Other critical data gaps are those categories that have not yet been characterized in areas where high usage have been observed. In summary, this analysis shows that additional information is needed on the following:

- Horizontal extent of WP on Racine Island. This data gap will not be addressed in 1995.
- Vertical extent of WP in areas with high waterfowl use. This data gap will not be addressed in 1995; however, a treatability study will be conducted to evaluate a

remotely controlled drill and sampler that may be used to assess vertical extent in the future.

- Off-site migration of WP. This data gap will not be addressed in 1995.
- Waterfowl and predator use in several areas. Telemetry studies and aerial surveys will performed again this year to track how frequently the ducks and eagles use the areas of the ERF.
- Lethal effects to waterfowl and predators in several areas. Telemetry studies will be performed this year to estimate the mortality rate across the ERF.
- Off-site receptor exposure and effects. This data gap will not be addressed in 1995.

Site characterization data needed to address the applicability of remedial technologies are outlined. Broad information categories include physical, chemical, biological, habitat, and replacement site. These are charted against the potential remedial technologies: dredging, pond drainage with natural attenuation, natural attenuation alone, AquaBlok™, liners, hazing, methyl anthranilate, cap / fill, excavation, and land purchase at a replacement site.

The qualitative evaluation that was performed to determine the importance of information in deciding which technologies are applicable to different areas of the ERF is summarized. For example, site access is an important issue in determining whether dredging can be performed in an area. Because pilot tests for several remedial technologies are being performed during the 1995 field season, the determination of critical data should be reconsidered before significant studies are initiated. More focus is needed on specific data needs for likely technologies and ERF remediation areas before a cost-effective study of the site characteristics can be prepared.

The qualitative analysis that was performed to identify data needed to support a remedial action decision is also summarized. The analysis used criteria to address the feasibility of remedial action that were based on nine evaluation criteria of the USEPA for choosing a remedial action under CERCLA. Particular aspects of the ERF—such as the importance of being able to operate a technology remotely to reduce the potential safety hazards of personnel operating in an area containing unexploded ordnance (UXO)—were emphasized.

**CH2M Hill** (1997) Operable Unit C. Final Feasibility Study Report. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. September.

This report presents the results of the Feasibility Study (FS) for Operable Unit C (OUC) on Fort Richardson, Alaska. Operable Unit C represents the Eagle River Flats (ERF) and the former open burning / open detonation (OB / OD) Pad area at Fort Richardson. The U.S. Army Corps of Engineers (COE), Alaska District, on behalf of the U.S. Army, Alaska (USARAlaska), contracted with CH2M Hill to prepare the FS under Delivery Order 1, Modification 5, of Contract Number DAC85–95-D0015.

*Site description and contamination*

Eagle River Flats is an 876-ha estuarine salt marsh at the mouth of Eagle River. Approximately 25 targets placed in ERF have been used for artillery training since 1949, creating thousands of craters in the wetlands and associated mud flats and leaving an estimated 100,000 unexploded mortar and artillery shells buried in the shallow subsurface. Although ERF is an active impact area, it remains a productive wetland that serves as an important staging ground for migrating waterfowl during the spring and fall migrations. ERF also supports local populations of fish, birds, mammals, and macroinvertebrates. A series of ponds distributed throughout ERF provide excellent habitat for dabbling waterfowl.

Since the initial reports of elevated waterfowl mortality in the early 1980s, a multidisciplinary investigation has been conducted to identify the cause of the mortality (shown in 1990 to be white phosphorus [WP]), the extent of the WP contamination, and the potential effects of WP and other munitions on the biota in ERF. WP was released into ERF by ordnance used to create smoke for marking. WP that does not fully oxidize can remain as particles in the sediment. Ingestion of WP particles by feeding waterfowl has created high levels of mortality. Birds have been observed to die within minutes to hours of ingesting WP in a number of ponds in ERF.

The results of the investigations to characterize the nature and extent contamination and the baseline risk assessment for the site were presented in the OUC remedial investigation (RI) report.

The findings documented in the RI report are based primarily on data collected before implementing the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) process at OUC. Compilation and review of all the data have led to the following conclusions:

- WP is the primary cause of waterfowl mortality.
- WP was deposited in the sediment primarily during range firing activities.
- Craters in ERF potentially indicate the level of range firing activity.
- WP particles are not homogeneous throughout ERF.
- The detection frequencies and concentrations for WP in sediment are highest in Area C, Bread Truck, and Racine Island.
- WP particles can break down (sublime / oxidize) when exposed to air, but are long lasting in water-saturated sediment.
- Waterfowl are exposed to WP from the sediment of ponds and sedge marshes while they are feeding.
- Dabbling ducks and swans are the primary receptors of WP.
- Predation and human exposure to WP by consumption are not high-level concerns at present.
- Permanent ponds, with associated sedge marsh, having confirmed presence of WP or moderate to high crater density and observed moderate to high dabbling duck and swan use are the most significant exposure areas (called hot ponds).
- The movement of WP through Eagle River to Knik Arm appears to be minimal.

*Open Burning/Open Detonation Pad*

Open Burning / Open Detonation Pad is about 3.2 ha (about 8 acres) in size and consists of a gravel pad placed as fill at the edge of ERF. Open burning and open detonations of explosive materials historically have occurred on this pad.

The following are major findings of the RI for OB / OD pad:

- The groundwater is at a depth of 6 to 11 m below the surface, the gradient is shallow, and groundwater moves toward the southwest, toward ERF.
- The site investigation detected only a limited number of organic chemicals and metals in the soil and groundwater.
- OB / OD Pad will meet clean closure requirements.
- The ecological and human health risk assessments found very low risks associated with exposures to these chemicals at the measured concentrations.

Because OB / OD Pad meets clean closure guidance from Title 40 of the Code of Federal Regulations, Part 264, and no significant environmental or human health risks were determined, remediation of OB / OD Pad is not included in the FS.

*FS process*

The OUC FS is intended to provide the U.S. Army Alaska, U.S. Environmental Protection Agency, and Alaska Department of Environmental Conservation (the Agencies) and the public with an assessment of the remedial alternatives, including their relative strengths and weaknesses. The overall goal is to provide sufficient information to the decision makers so that they can select a proposed alternative to be applied to OUC. The decisions will be used to develop a proposed plan and a Record of Decision (ROD) to achieve remediation at OUC. There were five steps used to prepare this FS:

- *Develop remedial action objectives (RAOs).* The overall remedial objective is the protection of the environment and human health.
- *Develop pond groups.* Twenty-two ponds at ERF were identified for remediation. They were divided into six pond groups on the basis of physical site characteristics and expectation of similar response to remediation. This pond grouping forms the geographical basis of making decisions.
- *Develop remedial alternatives.* Five remedial alternatives were developed.
- *Evaluate each remedial alternative against nine criteria as required by the National Contingency Plan* (NCP).
- *Compare alternatives for each pond groups.* This step involved evaluating how each alternative would perform under the NCP criteria at each pond group. Because of differing physical characteristics, each pond group is expected to perform differently under each alternative. Thus, a different alternative may be ultimately selected for each pond group.

*Remedial action objectives*

As introduced in the OUC RI report, the overall remedial objectives at ERF are the protection of the environment and human health. There are three specific RAOs:

- *Reduce dabbling duck mortality*. This RAO addresses the single most important issue associated with WP contamination. Because dabbling ducks have been the most affected, their mortality will be assessed specifically in support of the achievement of this goal. Mallards have been chosen as the indicator

species. The specific objective in 5 years is to reduce the mallard mortality rate by 50% compared to the value in 1996. The objective in 20 years is to reduce that mortality rate to no more than 1% above the reference value.
- *Reduce hot zones.* This RAO supplements the RAO for duck mortality. The number of hectares characterized as "hot" will be used to measure achievement of this objective. In general, a hot zone will be determined by a combination of duck mortality, WP concentrations or quantity, duck usage, and crater density. The specific objective is to reduce hot zones by 50% in 5 years and by 99% in 20 years compared to the number of hectares in January 1996.
- *Reduce WP exposure pathways.* This RAO will be used as the basis for measuring the success of remedial actions. It is technology-specific and designed to provide near-term feedback on the success of a specific remedial action performed at a specific area. The specific objective is no bioavailable WP for ducks and swans.

*Develop pond grouping*

The 22 hot ponds identified in the RI have been divided into six groups. This was done to aid in the evaluation of alternatives for the FS and to allow for the selection of different remedies at different pond groups based on the different characteristics of each group. These pond groups are as follows:

- Northern A (seven ponds).
- Pond 290 (one pond).
- Pond 183 (one pond).
- Pond 146 (one pond).
- Northern C and C/D Ponds (eight ponds).
- Ponds 109, 285, 293, and 297 (four ponds).

The first five groups were made based on nearby types of vegetation, topography, knowledge of the extent of contamination, and hydrologic interconnections. The ponds in each group have similar physical characteristics and are expected to a respond similarly to remedial actions. These five pond groups are separately evaluated in this FS.

The sixth group of ponds either have had treatment or will have treatment in 1997. Hence, these ponds will not be evaluated in this FS. They are included in the overall monitoring program for ERF.

*Development of remedial alternatives*

There were three steps in the development of remedial alternatives for this FS:

- Identify potential remedial technologies.
- Screen technologies.
- Assemble technologies into alternatives.

Technologies were identified that may be effective in reducing the impacts of the WP exposure at ERF. This may occur by reducing the concentration of WP in the sediment or by reducing the exposure of the receptors to WP. Fifteen potential technologies represented the range that was considered to be potentially feasible after many previous years of study and testing at ERF.

On the basis of information available from the treatability studies and vendors, the technologies were screened on the criteria of effectiveness, implementability, and cost. This screening resulted in 10 technologies being screened out and the following six retained:

- AquaBlok.™
- Detailed monitoring of natural processes.
- No action.
- Pond draining by breaching.
- Pond draining by pumping.
- Hazing.

The technologies that passed through screening were assembled into five alternatives, which were assembled to meet several objectives. First, the no action alternative was included as required by the NCP. Second, technologies were combined into action alternatives in such a way that the alternatives would be complete; that is, each alternative would address the range of exposure pathways identified for WP.

The five assembled alternatives are as follows:

- *Alternative 1, no action.* No remedial action or monitoring is performed.
- *Alternative 2, detailed monitoring.* No remedial action is performed, but detailed monitoring is conducted to observe whether natural processes that assist RAO success are occurring at the flats. Hazing is performed as a temporary interim measure.
- *Alternative 3, pumping and AquaBlok™.* Pumps are used to drain the pond groups so that the drying sediment can allow the existing WP to sublime–oxidize and therefore decrease concentrations. After 5 years of pond draining, AquaBlok™ is then spread over any remaining contaminated areas. Detailed monitoring is included in this alternative. Hazing is also conducted as a temporary interim measure.
- *Alternative 4, breaching, pumping, and AquaBlok™.* Ditches are first created to drain the ponds via existing gullies or Eagle River.

Pumps are also installed to drain areas of pond groups that do not drain via the man-made ditch. The pond draining allows the sediment to dry so that the existing WP can sublime–oxidize. After a few years of pond draining, AquaBlok™ is then spread over any remaining contaminated areas. Detailed monitoring is included in this alternative. Hazing is also performed as a temporary interim measure.
- *Alternative 5, AquaBlok™*. The product is applied over the surface area of the pond groups. Detailed monitoring is included in this alternative. Hazing is also performed as a temporary interim measure.

A review will be conducted after 5 years of remedy implementation and monitoring to determine whether RAOs are being met.

*Environmental impacts*

ERF supports a diverse community of waterfowl and shorebirds. Observations have shown that the ducks prefer specific types of habitat: sedge marsh, permanent ponds, and intermittent ponds. This preference for habitat types has been considered in this FS.

Remedial alternatives 3 and 4 involve draining the selected pond or pond group. These treatments are expected to modify ERF habitat to varying degrees. Pond draining by pumping (alternative 3) is expected to lead to only temporary changes in the habitat, whereas pond drainage by breaching (alternative 4) is expected to result in a more permanent change in habitat. High residual risk is expected to remain as a result of AquaBlok™ application under alternative 5.

A breached pond will fill and drain with lower high tides than a pond drained by pumping. Changes in plant species composition would be most dramatic under alternative 4 and will modify the habitat quality for selected bird species. In addition, it is unlikely that breached ponds can be restored. The erosion patterns that would be created over time reduce the feasibility of reversing the process and restoring the ponds (as permanent or intermittent ponds) once remediation of the ponds is completed.

*Monitoring strategy*

Because of the nature of the RAOs, the contamination at ERF, and the remedial alternatives, detailed monitoring will be necessary to determine if and when the RAOs will be met. The first RAO, reducing dabbling duck mortality, is not specific to an area of ERF or to the application of a specific remedial alternative. It must be achieved on the basis of information about ERF as a whole because the ducks have been observed to fly all over the flats, and WP has been detected in many areas. The following monitoring will be performed annually to improve understanding of the baseline condition and to determine progress toward achieving RAO number 1 for alternatives 2 through 5:

- *Telemetry*. As discussed in the RI report, birds are captured, small radio transmitters are attached to them, and then they are released in the area in which they were captured. In this study approximately 100 to 150 mallards will be tracked during the 2-month fall migration period.
- *Aerial bird population surveys.* Annual population surveys will provide knowledge of trends in the use of ERF, which can help in understanding specific or unusual results form the telemetry studies.
- *Aerial photography*. Aerial photography provides confirmation information about bird populations at specific ponds when it is coordinated with the aerial bird surveys.

The evaluation of RAO number 2, reduction of hot zones, is maintained by updating a yearly inventory of treated hot ponds that have successfully reduced WP exposure pathways in implementing alternatives 2 through 5. Monitoring for reduction in WP exposure pathways (the third RAO) will be achieved by sampling for WP and conditions that foster containment or sublimation–oxidation of WP in sediments.

*Detailed analysis*

The NCP requires that each alternative be analyzed on the basis of nine decision making criteria:

- Overall protection of human health and the environment.
- Compliance with applicable or relevant and appropriate requirements (ARARs).
- Long-term effectiveness and permanence.
- Reduction of toxicity, mobility, or volume through the use of treatment.
- Short-term effectiveness.
- Implementability.
- Cost.
- State acceptance.
- Community acceptance.

The first seven criteria are used in the detailed analysis of the remedial alternative in this FS. The last two will be evaluated following receipt of comments on this FS and the proposed plan from the public and government agencies. The last two criteria will be addressed in the ROD.

The detailed analysis was conducted for each pond group individually. This will allow for a determination of the applicability of each of the five alternatives to each pond group. Because of the differences among the pond groups, different alternatives may be better suited for different pond groups. This approach will provide the necessary information to the public and the RPMs to allow different remedies to be selected in different areas of ERF.

*Comparison of alternatives*

A comparative analysis of the alternatives was conducted for each pond group using the seven criteria that were used in the detailed analysis. For each pond group, the differences in the ability of each alternative to meet each criterion are presented. In addition, for each pond group, the alternatives are ranked in terms of their ability to meet each criterion.

The preferred alternatives for each pond group will be presented in the final Proposed Plan. The Draft Proposed Plan will available for public review and comment before the final selection of remedial alternatives.

**CH2M Hill** (1997) Operable Unit C. Final Remedial Investigation Report. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska, May.

This report presents the results of the remedial investigation (RI) for Operable Unit C (OUC) on Fort Richardson, Alaska. The U.S. Army Corps of Engineers (COE), Alaska District, on behalf of the U.S. Army, Alaska (USARAlaska), contracted with CH2M Hill to prepare the RI report under Delivery Order Number 1, Modification 3, of Contract Number DAC85-95-D0015.

Fort Richardson is an active U.S. Army installation near Anchorage, Alaska. It encompasses 22,260 ha along the Knik Arm of the Cook Inlet, immediately east of Elmendorf Air Force Base and the Municipality of Anchorage. In June 1994, Fort Richardson was listed by the U.S. Environmental Protection Agency (USEPA) on the National Priorities List (NPL). This listing designated the post as a Federal Superfund site subject to the remedial response requirements of the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA), as amended by the *Superfund Amendments and Reauthorization Act* of 1986.

As a result of the listing of Fort Richardson on the NPL, the USARAlaska, USEPA, and the Alaska Department of Environmental Conservation negotiated the Federal Facility Agreement for Fort Richardson, which all three parties signed on 5 December 1994. Under the terms of the FFA, all remedial response activities will be conducted to protect public health and welfare, and the environment, in accordance with CERCLA, the National Contingency Plan, the *Resource Conservation and Recovery Act*, and applicable state law.

Fort Richardson was divided into four Operable Units (OUs), labeled A through D, as part of the FFA. Each OU encompasses a series of potentially contaminated sites identified during an inventory that was completed before the FFA was signed. This report documents RI results for OUC, which includes the primary ordnance impact area on Fort Richardson (Eagle River Flats [ERF]) and an adjacent gravel pad that was used for the open burning (OB) and open detonation (OD) of unwanted ordnance (OB/OD Pad).

*Eagle River Flats*

Eagle River Flats is an 876-hectare estuarine salt marsh at the mouth of Eagle River. Approximately 25 targets placed in ERF have been used for artillery training since 1949, creating thousands of craters in the wetlands and associated mud flats and leaving an estimated 100,000 unexploded mortar and artillery shells buried in the shallow subsurface. Although ERF is an active impact area, it remains a productive wetland that serves as an important staging ground for migrating waterfowl during the spring and fall migrations. ERF also supports local populations of fish, birds, mammals, and macroinvertebrates. A series of ponds distributed throughout ERF provide excellent habitat for dabbling waterfowl.

Since the initial reports of elevated waterfowl mortality in the early 1980s, a multidisciplinary investigation has been conducted to identify the cause of the mortality (shown in 1990 to be white phosphorus [WP]), the extent of the WP contamination, and the potential effects of WP and other munitions on the biota in ERF. WP was released into ERF by ordnance used to create smoke for ground troop cover. WP that does not fully oxidize can remain as particles in the sediment. Ingestion of WP particles by feeding waterfowl has created high levels of mortality. Birds have been observed to die within minutes to hours of ingesting WP in a number of ponds in ERF.

Sampling results have focused primarily on a relative small number of areas in ERF where the greatest levels of mortality were observed. The results of this sampling have demonstrated that elevated levels of WP exist in most ponds where the highest mortality levels occur; however, in some ponds where high mortality has been observed, WP has not been extensively detected in the sediment. This finding suggests that some birds may ingest WP in a contaminated area but fly away from the point of exposure before succumbing. The potential for birds to move following exposure, coupled with limitations on sampling efforts because of the hazard posed to site workers by the unexploded ordnance (UXO), has complicated delineation of the lateral and vertical extent of WP contamination.

Previous sampling results and detailed observation of various populations within ERF have identified waterfowl as the primary receptors of WP contamination. Although low levels of WP have been found in plants, macroinvertebrates, and fish, existing data do not show that these populations have been significantly affected by the presence of WP in ERF. There is some evidence indicating that scavengers that feed on waterfowl carcasses in ERF, particularly bald eagles, may have been affected by WP. It is believed, however, that reducing the acute effect in dabbling waterfowl (mortality) to acceptable levels also will reduce potential effects (acute or chronic) in the predators and scavengers that have been identified as secondary receptors because of the reduction in their exposure concentrations. Therefore, the primary preliminary remediation goal for ERF is the reduction of mortality in dabbling ducks and swans.

Observations of carcass locations, areas preferred by waterfowl, and crater densities were used by researchers to define areas most likely to contain WP. The sediments in these areas were extensively sampled for WP, with the use of radial transects in open ponds. The distribution of ponds, and analytical results of WP in sediment, were compiled and used in conjunction with landcovers (combination of landform and vegetation) and bird usage data to identify hot ponds that are likely the area presenting the highest risk. The UXO hazard in ERF, in combination with the high sampling frequency, makes extensive future sampling efforts infeasible.

The findings documented in this report are based primarily on data collected before implementing the CERCLA process at OUC. However, the analytical process for the identification of WP concentrations was first developed during this phase and has since been adopted by the USEPA as Method 7580 in SW 846 Update III. Compilation and review of these data have led to the following conclusions:

- *WP is the primary cause of waterfowl mortality.* Symptoms exhibited by exposed ducks in ERF are similar to those observed in ducks dosed with WP in the laboratory. WP also was detected in tissue samples collected from duck carcasses found in ERF.
- *WP was deposited in the sediment primarily during range firing activities.* WP smoke munitions were used during training activities in ERF for several decades. Rounds were fired onto the flats and detonated, dispersing WP particles over large areas. Further distribution of the particles likely occurred when high-explosive rounds exploded in WP-contaminated soil and sediment.
- *Craters in ERF potentially indicate the level of range firing activity.* Detonation of HE munitions generally creates a crater at the point of impact. Although WP munitions do not form craters upon detonation, they typically have been used in conjunction with HE training activities. By applying a cause-and-effect approach, it can be deduced that the more craters in an area, the more munitions that have likely been fired there, and thus the higher probability of WP contamination.
- *WP particles are not homogeneous throughout ERF.* WP particles are dispersed after munitions containing WP are detonated. Particle sizes vary because of the nature of an explosive release. Particle size, dispersion pattern, and ultimate resting location also depend on whether the munitions were detonated on land or over water. Even within small areas, the particle density can vary substantially.
- *The detection frequencies and concentrations for WP in sediment are highest Area C, Bread Truck, and Racine Island.* Of the overall ERF sampling locations, 63% had no detectable concentrations, but at least 45% of the locations in each of these three areas had detectable concentrations. The highest concentration, 3071 mg/g, was found on Racine Island.
- *WP particles can break down (sublime) when exposed to air, but are long lasting in water-saturated media.* WP particles are readily oxidized when exposed to air at temperatures exceeding 20°C. Because they dissolve so slowly, particles have an indefinite life when

quenched in the water and allowed to settle into pond or marsh bottom sediments.

- *Waterfowl are exposed to WP from the sediments of ponds and sedge marshes while they are feeding.* Some WP particles match the size of food (such as seeds and macroinvertebrates) sought by dabbling ducks and swans. As the waterfowl forage for food in pond and marsh bottom sediments, it is possible that they cannot differentiate between WP and their normal food source.
- *Dabbling ducks and swans are the primary receptors of WP.* Dabbling ducks and swans both forage for food in pond and marsh bottom sediments. In addition, mortality rates of dabbling ducks have been observed to be significantly higher than mortality rates of other waterfowl in ERF as well as other Upper Cook Inlet marshes. Telemetry data in 1996 suggest that the mortality rate among mallards was about 35%.
- *Predation and human exposure to WP by consumption are not high-level concerns at present.* There has been no verified mortality resulting from predators feeding on WP-contaminated waterfowl carcasses. Although a dead eagle has been found with WP contamination, current predator mortality appears low. In addition, the results of analyses of tissue collected from dabbling ducks taken by hunters near ERF do not indicate a threat to humans ingesting the meat.
- *Permanent ponds and associated sedge with confirmed presence of WP or moderate to high crater density and observed moderate to high dabbling duck and swan use are the most significant exposure areas (such as ponds are referred to as hot ponds).* According to the conceptual site model, areas of greatest concern are where there is a source (WP-contaminated sediment), a receptor (dabbling duck or swan), and a potential for exposure (foraging for food). Twenty-two hot ponds, which include a total area of 23 ha, have been identified in these areas: A, C, C/D, Bread Truck, and Racine Island.
- *The movement of WP through Eagle River to Knik Arm appears to be minimal.* WP has been detected in the sediments traveling through the gullies, but there is no evidence to suggest that WP would be detected in Knik Arm.

An integrated process of evaluating remedial success for ERF should be implemented once remedial action is initiated. Data specific to the remedial technology applied at a hot pond should be used as a preliminary indication that a hot pond has been eliminated. The future monitoring activities should become primary mechanisms for evaluating the main remedial goal of reducing waterfowl mortality over the entire ERF.

*OB/OD Pad*

OB/OD Pad is about 4 ha in size and consists of a gravel pad as fill on the edge of ERF. Open burning and detonation of explosive materials historically have occurred on this pad. Materials have included fuses, high-explosive projectiles, smoke pots, mortar rounds, star cluster, flares, mines, rocket motors, shaped charges, detonation cord, dynamite, and some flammable solids. Existing records indicate that no liquids were disposed of there. Disposal was either on the surface or in an excavated pit.

A site investigation of the soil and groundwater at OB/OD pad was completed in 1996. Surface and subsurface soils were sampled. Nine monitoring wells were installed and developed, and groundwater samples were taken. Soil and ground water samples were analyzed for an extensive list of volatile and semivolatile organic chemicals and metals. Very few chemicals were detected in either the soil or the groundwater. All detected chemicals had concentrations considerably below their action levels for clean closure. In addition, the ecological and human health risk assessments indicate that the risks are very low.

The following are major findings for OB/OD Pad:

- *The groundwater is at a depth of 6 to 11 m below the surface, and the gradient is shallow, with groundwater moving toward the southwest, toward ERF.* Groundwater movement patterns are likely influenced by the tides and the river.
- *The site investigation detected only a limited number of organic chemicals and metals in the soil and groundwater.* In many cases, observed soil concentrations were similar to reference area values.
- *The OB/OD Pad will meet clean closure requirements.* The detected chemicals were all considerably below their clean closure action levels.
- *The ecological and human health risk assessments found very low risks associated with exposures to these chemicals at the measured concentrations.*

At OB/OD Pad, the USARAlaska should proceed with clean closure in accordance with the requirements in the closure guidance from Title 40 of the *Code of Federal Regulations*, Part 264. The U.S. Army Alaska may consider the use of the ERF dredge spoils as cap material.

*Organization of report*

The organization and content of this RI report are described as follows:

- *Section 1, Introduction*, briefly describes where the RI fits in the CERCLA process and summarizes the purpose and objectives of the RI. Included are a brief history of OUC source areas and other relevant background information.
- *Section 2, Environmental Setting*, describes the physical and ecological features of OUC, including location, climate, geology, soils, hydrology, aquatic and terrestrial ecology, and military and civilian land use.
- *Section 3, Review of Studies*, provides a chronological summary of investigations at ERF, including a discussion of sampling location, number, and type; laboratory analytical methods; and quality assurance (QA)/quality control (QC) measures.
- *Section 4, Nature and Extent of Contamination*, presents the results of the sampling and analysis for WP in ERF (water, soil, and sediment).
- *Section 5, Conceptual Site Model*, presents the conceptual model for ERF, identifying the sources of contamination when possible, contaminant characteristics and release mechanisms, and environmental fate and transport pathways. The conceptual model is based on data obtained from the RF, previous studies, and relevant technical literature.
- *Section 6, OB/OD Pad*, presents information on historical use of OB/OD Pad and a discussion of the 1996 site investigation, including sampling logic, locations, sample collection, laboratory analytical methods, QA/QC procedures, and results of the sampling and analysis of soil and groundwater. A conceptual site model based on results of the site investigation is also presented for OB/OD Pad.
- *Section 7, Comparison of ARARs*, summarizes chemical- and location-specific ARARs pertinent to ERF and OB/OD Pad.
- *Section 8, Baseline Risk Assessment*, presents a summary of the evaluation of the threat to human health and the environment as a result of the contamination identified at OUC. The detailed evaluation, including in Appendices A and B, is based on data obtained from the RI and is consistent with the conceptual site models (CSMs) presented in sections 5 and 6 and current USEPA guidance on baseline risk assessments.
- *Section 9, Conclusion and Recommendations*, summarizes the findings presented in sections 4 through 8, including the nature and extent of contamination, contaminant fate and transport, and the risk assessment. Contaminants of concern are identified and recommendations for further monitoring or remediation are presented.
- *Section 10, Preliminary Remediation Goals*, outlines the general and specific objectives for OUC remediation. Discussions of contamination hot spot identification and verification of remedial success also are presented. The discussions will form the basis for the subsequent FS.
- *Section 11, Works Cited*, lists all references cited in the RI report.
- *Appendices* contain the following reports and supporting data:
  - *Appendix A, Ecological Risk Assessment.*
  - *Appendix B, Human Health Risk Assessment.*
  - *Appendix C, Site Studies for Chemicals other than White Phosphorus.*
  - *Appendix D, Quality Assurance Audits.*
  - *Appendix E, OB/OD Pad Site Investigation Data.*
  - *Appendix F, Response to Comments.*

**CH2M Hill** (1998) Proposed Plan for Cleanup Action at Operable Unit C, Fort Richardson, Alaska. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska, February.

This Proposed Plan presents cleanup alternatives for Operable Unit C (OU-C) at Fort Richardson near Anchorage, Alaska. These alternatives are being considered by the U.S. Army, the Alaska Department of Environmental Conservation (ADEC), and the U.S. Environmental Protection Agency (EPA). The Army, ADEC, and EPA are soliciting comments from the public on the information and proposed cleanup actions discussed in this document. For your convenience, this Proposed Plan contains as alphabetical glossary of terms that defines the words and abbreviations printed in ***bold italic*** type.

Although this Proposed Plan identifies a preferred alternative for the Eagle River Flats (***ERF***) site, a final decision will not be made until the public comment period ends and all comments are reviewed and considered. The public is encouraged to review and comment on all alternatives presented in this Proposed Plan.

Documents produced under the *Comprehensive Environmental Response, Compensation, and Liability Act* (***CERCLA***), such as the Ecological Risk Assessment (***ERA***), Remedial Investigation (***RI***), and Feasibility Study (***FS***), were prepared in coordination with the Biological Technical Assistance Group (***BTAG***). The BTAG consists of individuals from the Alaska Department of Fish and Game, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, and EPA.

The two sites in OU-C are the former Open Burning/Open Detonation (OB/OD) Pad and ERF, an ***ordnance*** impact area. Site investigations performed at the OB/OD Pad indicate that the contaminants found do not pose a threat to human health or the environment and do not require cleanup action. Therefore, except for ***institutional controls***, no cleanup action is recommended for the OB/OD Pad.

Site investigations performed at ERF found that ***white phosphorus particles*** were causing waterfowl deaths. Results were used to identify 18 ponds for cleanup. The preferred cleanup alternative for ERF includes a combination of 1) monitoring waterfowl use, the presence of contamination, the changing physical conditions at contaminated ponds at ERF; and 2) temporarily draining contaminated ponds with pumps followed by application of a cap-and-fill material where contamination remains.

**CH2M Hill** (1998) Record of Decision for Operable Unit C, Fort Richardson, Alaska. Contract Report to U.S. Army Corps of Engineers, Alaska District, and U.S. Army, Alaska. September.

This Decision Summary provides an overview of the problems posed by the contamination at Fort Richardson Operable Unit C (OU-C) source area. This summary describes the physical features of the site, the contaminants present, and the associated risks to human health and the environment. The summary also describes the remedial alternatives considered at OU-C; provides the rationale for the remedial actions selected; and states how the remedial actions satisfy the *Comprehensive Environmental Response, Compensation, and Liability Act* of 1980 statutory requirements.

The United States Army (Army) completed a Remedial Investigation (RI) at OU-C to provide information regarding the nature and extent of contamination in the soils and groundwater. A baseline Human Health Risk Assessment and Ecological Risk Assessment were developed and used in conjunction with the RI to determine the need for remedial action and to aid in the selection of remedies. A Feasibility Study was completed to evaluate remedial options.

*Statement of basis and purpose*

This Record of Decision (ROD) presents the selected remedial actions for Operable Unit C (OU-C), which consists of two source areas: the Eagle River Flats (ERF) and the former Open Burning/Open Detonation (OB/OD) Pad. This ROD was developed in accordance with the *Comprehensive Environmental Response, Compensation, and Liability Act* of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986; 42 *United States Code* 9601 *et seq.*, and, to the extent practicable, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 40 *Code of Federal Regulations* 300 *et seq.* This decision is based on the Administrative Record for OU-C.

The Army, the United States Environmental Protection Agency (EPA), and the State of Alaska, through the Alaska Department of Environmental Conservation (ADEC), have agreed to the selected remedies.

*Assessment of the site*

Actual or threatened releases of hazardous substances resulting from white phosphorus contamination of the ERF source area of OU-C, if not addressed by implementing the response actions selected in this ROD, may present an imminent or substantial threat to public health, public welfare, or the environment. ERF is contaminated with white phosphorus particles.

*Description of the selected remedy*

OU-C is the third OU to reach the final-action ROD at the Fort Richardson National Priorities List site. This ROD addresses sediment contamination at the ERF source area of OU-C.

No further action is selected for the former OB/OD Pad for hazardous chemicals. Because of concerns about potential human exposure to unexploded ordnance, the Army has institutional controls that provide monitoring and control of access to the site. These controls are required to remain in place. No analysis of remedial alternatives was conducted for the OB/OD Pad source area. A discussion of the OB/OD Pad is provided in Section 9 of this ROD.

The remedial action objectives (RAOs) for the ERF are designed to accomplish the following:

- Within 5 years of the ROD being signed, reduce the dabbling duck mortality rate attributable to white phosphorus to 50% of the 1996 mortality rate attributable to white phosphorus. Radio tracking and aerial surveys suggest that about 1000 birds died from white phosphorus at ERF in 1996. Therefore, the allowable number of duck deaths from white phosphorus would be approximately 500.
- Within 20 years of the ROD being signed, reduce the mortality attributable to white phosphorus to no more than 1% of the total annual fall population of dabbling ERF ducks. Currently, that population is about 5000. Therefore, the allowable number of duck deaths from white phosphorus would be approximately 50. This long-term goal could be adjusted based on future population studies conducted during the monitoring program.

These objectives will be achieved by reducing the area of white phosphorus-contaminated media and reducing the exposure to white phosphorus. Reducing the exposure will reduce the availability of white phosphorus to ducks, which in turn will reduce duck deaths.

Monitoring at ERF will be conducted to verify that RAOs are achieved. The following are goals of monitoring:

- To verify that an exposure pathway does not exist between waterfowl and white phosphorus-contaminated sediment.
- To determine the number of waterfowl using ERF.
- To determine the number of waterfowl dying as a result of feeding in white phosphorus-contaminated sediment.
- To determine whether remedial action is effective or needs modification.

The major components of the preferred remedy for OU-C are listed below. It is assumed that implementation of the remedy will begin in 1999 and end in 2018 (duration of 20 years). Treatment will occur between 1999 and 2003, and will be followed by long-term monitoring from 2004 to 2018.

- Treat white phosphorus-contaminated sediment by draining ponds with pumps for five summers beginning in 1999. Pumping would allow the sediments to dry and the white phosphorus to sublime and oxidize. The treatment season would begin in May and end in September. A pond elevation survey would be conducted to determine the optimal pump placement. To enhance drainage, explosives may be used to make small sumps for the pumps and shallow drainage channels. These shallow drainage channels would enhance hydraulic connectivity between ponds to encourage drainage.
- Implement the following protective procedures to minimize disturbances to wetlands habitat:
  - Restriction of activities that disturb wildlife in Area B and Area D, which are prime waterfowl habitat areas.
  - Selection of the narrowest and shortest walking corridors to minimize disturbances to vegetation and habitat.
  - Proper maintenance of equipment and structures.
  - Minimization of the use of equipment and of staging-area footprints.
  - Minimal localized use of explosives.
  - Preparation of work plans and solicitation of agency reviews.
  - Monitoring for impacts to wetlands habitat.

*Monitoring for waterfowl use of ERF*

- Sample pond bottoms for white phosphorus at the beginning of the treatment season to confirm or determine that the pond or area requires remediation. The sampling also would establish a white phosphorus baseline and determine additional areas that may require remediation. The baseline sampling would be performed at the beginning of each field pumping season (every year for the first 5 years, starting in 1999).
- Sample pond bottoms for white phosphorus after treatment to determine effectiveness of the treatment system. This verification sampling would be performed at the end of each field pumping season (every year for the first 5 years, starting in 1999).
- Perform telemetry monitoring and aerial surveys every year for the first 5 years concurrently with pumping activities to determine bird populations, usage, and mortality. These activities would begin in 1999. Monitoring would be continued for 3 additional years to

verify that short-term goals are maintained. Monitoring also would be conducted at years 10, 15, and 20 to ensure that remedial action objectives continue to be maintained.

- Perform limited aerial surveys and ground truthing during years 9 to 20 to evaluate waterfowl mortality, physical habitat changes, and vegetation rebound.
- Perform aerial photography every other year for 10 years (beginning in 1999) to monitor habitat changes resulting from remedial actions. Changes in drainage, topography, and vegetation would be evaluated.
- Perform habitat mapping once every 4 years for 20 years to evaluate impacts to habitat as a result of remedial actions, as well as to observe physical habitat changes and vegetation rebound after pumping is discontinued.
- Perform limited hazing (only as a contingency) during first 5 years starting in 1999 if incidental hazing from pumping operations and other fieldwork activities does not deter bird usage.
- After remedial action objectives are achieved and pumping is discontinued, apply cap-and-fill material in ponded areas that did not drain and dry sufficiently to enable the white phosphorus to sublime and oxidize. Cap-and-fill material placement is expected to occur in year 5 (2003).
- Monitor cap and fill material integrity every year for 4 years after the material is placed, and also at years 10, 15, and 20.
- Incorporate white phosphorus sampling, telemetry, aerial survey, habitat, and physical landform data into a geographical information system (GIS) database. Perform GIS management every year for the first 8 years, starting in 1999, and then during years 10, 15, and 20.
- Maintain institutional controls, including the restrictions governing site access, construction, and road maintenance and the required training for personnel who work at OU-C source areas, as long as hazardous substances, and unexploded ordnance hazards, exist at OU-C.

*Statutory determination*

The selected remedy is protective of human health and the environment, complies with Federal and state requirements that are legally applicable or relevant and appropriate to the remedial action, and is cost-effective. The remedy uses permanent solutions and alternative treatment technologies to the maximum extent practicable, and satisfies the statutory preference for remedies that employ treatment that reduces toxicity, mobility, or volume as a principal element.

Because the remedy will result in hazardous substances that present a substantial ecological risk remaining on site, a review will be conducted within 5 years after commencement of the remedial action to ensure that the remedy continues to provide adequate protection of human health and the environment. Review will continue for 5-year increments until the RAOs are complete.

---

## CONFERENCE PAPERS

**Bigl, S.R., D.E. Lawson, and L.E. Hunter** (1997) Sediment accumulation at Eagle River Flats, Fort Richardson, Alaska. In *Proceedings, Cook Inlet Symposium, Anchorage, Alaska*, p. 3.

Eagle River Flats is an 865-ha salt marsh and a U.S. Army artillery range in upper Cook Inlet, where ingestion of white phosphorus (WP) from illumination rounds caused high rates of mortality in bottom-feeding waterfowl. Physical systems were studied as part of the site characterization to monitor their possible effects on proposed remediation efforts and to evaluate the potential for natural remediation through burial. We documented the duration and depth of tidal inundation, river–tidal interactions, and sediment transport at sites in ponds and in tidal creeks linking ponds to the Eagle River or to Knik Arm. Semidiurnal flooding during high spring tidal events inundates ponds and mudflats and drives surface hydrology. Flooding events have a higher frequency than predicted (from Anchorage tide data) during periods of peak glacial meltwater production. We measured sediment accumulation rates with various techniques in ponds and mudflats between 1992 and 1996. The primary sediment source is the tides from Knik Arm and sediment accumulation rates in ponds averaged 5 to 15 mm / yr. Higher accumulation rates (20 to 30 mm / yr) were observed on the mudflats near sources (Knik Arm coastal zone, Eagle River, tidal creeks). These relatively rapid accumulation rates may bury the WP sufficiently so that, over time, exposure of feeding waterfowl will be reduced.

**Bigl, S.R., D.E. Lawson, L.E. Hunter, B.M. Nadeau, P.B. Weyrick, and J.H. Bodette** (1995) Tidal flooding dynamics, sedimentation, and implications to site remediation, Eagle River Flats, Ft. Richardson, Alaska. In *Proceedings, Geological Society of America, Fairbanks, Alaska,* p. 6.

Eagle River Flats is an 865-ha subarctic estuarine salt marsh and impact area used by the U.S. Army-Alaska. High rates of mortality in migrating waterfowl during the 1980s and 1990s had led to extensive environmental study. Investigations by CRREL identified that small particles (~1 mm) of white phosphorus (WP), from artillery illumination rounds, ingested by waterfowl feeding from pond bottoms was the cause of observed high mortality rates. High levels of WP contamination remain despite cessation of firing of WP-bearing munitions in February 1990.

Investigations of physical system dynamics as part of the site assessment are to develop physical models of the depositional system and WP fate in the system, and to evaluate system response to remediation. Sedimentary processes and system dynamics are important because they affect the timing and distribution of tidal flooding and associated pond–mudflat sedimentation. Instrumentation located in gullies linking ponds–mudflats and the Eagle River document duration of inundation (depth), river versus tidal domination (salinity / temperature), and sediment transport (optical backscatter and total suspended solids). Sedimentation rates were also measured with various techniques.

Semidiurnal flooding during high tidal events causes pond–mudflat inundation and drives surface hydrology. Ponds receive sediment influx from riverine and tidal sources at accumulation rates of 10–30 mm / yr. These rapid rates may provide a means for natural remediation of WP contamination while enhancing the efficiency of artificial covers, geotextiles, or other capping methods. Amplification of tidal height by fjord geometry results in a higher frequency of flooding events than predicted from Anchorage tides. The result is repeated flooding and retardation of natural WP decomposition that is favored by warm, dry conditions. Further understanding of physical system dynamics is required to evaluate the best means for site remediation.

**Bird, S.T., C.H. Racine, M.E. Walsh, C.M. Collins, D.J. Calkins, B.D. Roebuck, L.W. Metker, and R. Newsome** (1991) Waterfowl mortality in Eagle River Flats, Alaska: The role of munitions compounds and human health risk assessment. In *Proceedings, Caribbean Haztech International Conference and Exhibition, 13–15 November, San Juan, Puerto Rico,* p. 1A–1.

Since August 1982, an estimated 1000–2000 waterfowl deaths have been observed each year at Eagle River Flats, a 2500-acre estuarine salt marsh complex on Cook Inlet near Anchorage, Alaska. This salt marsh has been used since 1949 as the primary impact area for artillery training by the military at Fort Richardson. Eagle River Flats is inhabited by waterfowl primarily during spring and fall migrations when the deaths have been observed. In the spring of 1990, the Army investigated the possibility that munitions compounds fired into the salt marsh were the cause of the mortality. Because no chemicals analyzed for showed elevated levels, the Army initiated a physical gross analysis of several selected sediment samples. The physical gross analysis was designed to investigate and distinguish between naturally occurring and foreign particles within the glacial sediments. In the summer of 1991, a sediment sample being prepared for visual inspection by the Army released a white puff of smoke upon stirring. White smoke is characteristic of white phosphorus (WP) munitions and immediately led the Army to consider WP as a possible cause of the waterfowl mortality and conduct a search of available literature on the toxicity of WP to waterfowl. At this point, WP became the prime suspect of the waterfowl mortality. The WP does not exist in nature since it spontaneously oxidizes in the presence of oxygen to form phosphorus oxides. When applied to well-drained upland soils, WP has been shown to oxidize and even provide a source of phosphate to growing plants. However, when smoke-producing munitions introduce WP particles into a salt marsh environment with anaerobic sediments and standing water, incomplete combustion and storage in the sediments is possible. The Army conducted both field and laboratory studies of waterfowl and sediments from Eagle River Flats and made an assessment of the toxicity of WP in the laboratory. (This is a truncated version of the *Introduction*. The conference paper did not have an abstract.)

**Collins, C.M.** (1997) Pond draining to treat white phosphorus-contaminated sediments at Eagle River Flats, Alaska. In *Proceedings, 5th International*

*Symposium on Cold Regions Development, American Society of Civil Engineers, 4–10 May, Anchorage, Alaska*, p. 179–182.

Eagle River Flats is an estuarine salt marsh located on Ft. Richardson near Anchorage, Alaska. For 50 years, it has been used as an ordnance impact area by the Army. During the 1980s, large die-offs of waterfowl occurred in this area during spring and fall migrations. For 5 years, various state and Federal agencies tried without success to unravel the mystery of this high mortality. Finally, in the spring of 1990, a group of researchers from CRREL, working in conjunction with the Ft. Richardson Directorate of Public Works, Environmental Branch (DPW-EV), discovered that white phosphorus was the cause of the waterfowl mortality. White phosphorus ($P_4$ or WP) has been used in the past by the Army as a targeting and obscurant round.

Eagle River Flats is part of the Ft. Richardson Superfund site, and this work was performed in accordance with the U.S. Government *Comprehensive Environmental Response, Compensation, and Liability Act*. The primary sponsor is the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland. Support was provided by the U.S. Army Corps of Engineers, Alaska District, and the U.S. Army Alaska (DPW-EV).

**Collins, C.M., C.H. Racine, and M.E. Walsh** (1992) White phosphorus contamination of an Alaskan salt marsh: Eagle River Flats. In *Proceedings, American Water Resources Association—Alaska Section Annual Meeting, 9–10 April, Fairbanks, Alaska*, p. 99.

In 1990 we identified elemental or white phosphorus as the toxicant responsible for the death of several thousand dabbling ducks each year in Eagle River Flats, a salt marsh wetland on Ft. Richardson. Eagle River Flats is the artillery impact area for Ft. Richardson and the white phosphorus particles were deposited from smoke projectiles fired into the impact area. Burning white phosphorus is extinguished when immersed in water, leaving a significant amount (10–30%) of unreacted white phosphorus in the burn residue. The saturated sediments and anaerobic conditions found in the shallow ponds within the salt marsh leads to the preservation of the unburned white phosphorus. Particles of white phosphorus isolated from the fine silt and clay sediments ranged from 0.26 to 2.9 mm in length. Most of the particles isolated were greater than 0.5 mm in length, and thus are in the size range of food items such as seeds or invertebrates selected by ducks. Since a lethal dose of white phosphorus is on the order of 1 mg/kg of body weight, the ingestion of one particle can be fatal to a duck. Contamination in the 1000-ha ERF was mainly confined to four small pond areas totaling approximately 30 ha. Our findings are significant since Eagle River Flats is the first artillery training area identified to be contaminated with white phosphorus. Previous to our investigations, white phosphorus was thought to be nonpersistent in the environment because it is thermodynamically unstable in the presence of oxygen. However, the anaerobic sediments of a wetland provide ideal conditions under which white phosphorus can persist indefinitely.

**Collins, C.M., and M.E. Walsh** (1995) The effects of environmental conditions on the persistence of white phosphorus particles in Eagle River Flats, Alaska. In *Proceedings, The 1995 Annual Conference of American Water Resources Association, 6–7 April, Juneau, Alaska*, p. 57.

Eagle River Flats, Fort Richardson, Alaska, is the first Army training area identified with white phosphorus ($P_4$) contamination. White phosphorus is highly toxic and has been responsible for large numbers of waterfowl deaths in Eagle River Flats. Recent surveys at other army training areas have also revealed white phosphorus contamination. Previous to our findings at Eagle River Flats, white phosphorus was thought to be nonpersistent in the environment, indicating that the current understanding of the environmental fate of white phosphorus is poor. White phosphorus particles up to several millimeters in size were deposited in the salt marsh sediments of Eagle River Flats from the incomplete combustion of white phosphorus smoke munitions. Remediation of sediments at Eagle River Flats may require severe alterations of the wetland by dredging, draining, or covering. However, some sediments may undergo decontamination naturally in areas that are seasonally subaerially exposed. To predict the persistence of white phosphorus in sediments, laboratory and field experiments were conducted. White phosphorus particles were found to be persistent indefinitely in saturated sediments. In unsaturated sediments, loss was rapid (within 24 hours) at 20°C, and retarded by low temperatures. This information is being used to plan remediation strategies for Eagle River Flats. Limitation of remedial actions to those areas where white phosphorus is persistent and will continue to threaten wildlife would make the remedial process more efficient and less controversial.

**Collins, C.M., M.E. Walsh, and M.R. Walsh** (1997) Pond draining and sediment drying as a remediation of white phosphorus contaminated sediments in wetland, Ft. Richardson, Alaska. In *Proceedings, SETAC 18th Annual Meeting, 16–20 November, San Francisco, California,* p. 124.

Deposition of white phosphorus in the saturated wetland sediments and shallow ponds of the Eagle River Flats Firing Range on Ft. Richardson, Alaska, has resulted in the deaths of large numbers of dabbling waterfowl. Shallow pond areas within Eagle River Flats where waterfowl feed are ideal locations for preserving white phosphorous and are the sites of greatest mortality. If these contaminated sediments are exposed to the atmosphere and allowed to dry, the solid white phosphorus particles will sublime and the vapor will oxidize. Draining of ponds to expose the contaminated sediments is being undertaken in two treatability studies. The first involves permanent draining through ditching. Because unexploded ordnance is distributed throughout the area, military explosives were used during the early spring to excavate an 80-m and a 130-m-long ditch between two contaminated ponds and nearby drainage gullies. The contaminated sediments were then allowed to dry. Soil moisture and temperature conditions were monitored to ascertain if conditions were conducive to the sublimation of white phosphorous particles. A second, less destructive treatability study uses a large dewatering pump to pump the water out of a contaminated pond. Water is kept out of the pond throughout the warmest part of the summer by repeated pumping to allow contaminated pond bottom sediments to dry out. Soil moisture and temperature conditions were also monitored to determine sublimation rates of white phosphorous particles. For both treatability studies, the sediments were sampled at the end of the season and analyzed for white phosphorous to assess effectiveness of the remediation strategies.

**Collins, C.M., M.R. Walsh, M.E. Walsh, J.T. Walls, and M.E. Wong** (in press) Remediation of a white phosphorus contaminated salt marsh: Eagle River Flats, Alaska. In *Proceedings, 1999 International In Situ and On-Site Bioremediation Symposium, 19–22 April, San Diego, California.*

Pond pumping treatability studies were conducted at ERF in the summers of 1997 and 1998. Pond pumping is a way to temporarily drain the ponds, allowing the sediments to desaturate and the $P_4$ to sublime. Pond pumping does not permanently alter the environment the way ditching and dredging do. Six automatic remote pumping systems have been designed for Eagle River Flats: one 1000-gallon-per-minute (gpm) system (powered by a 50-kW diesel generator), four 2000-gpm systems (80 kW), and one 3000-gpm system (125 kW). The pumping systems consist of two units: a 15-cm (6-in.) open-impeller centrifugal pump on floats and a generator set (genset) with fuel tanks, also on floats. A series of float switches automatically turns the pump system on and off as water levels change. Units are sized to allow air transport into remote ponds using UH–60 Blackhawk helicopters. In 1997, one pumping system was operated at ERF, and in 1998 all six systems were deployed.

The automatic pump system was highly successful in keeping the treated ponds drained for much of the summer. This resulted in extensive drying of the exposed pond bottom sediments. Following treatment in 1997, $P_4$ concentrations decreased by over 88% in the pond treated. Laboratory manufactured $P_4$ particles were planted in the sediment during the 1997 and 1998 treatment seasons. The planted particles decreased in mass by 50% in 1997, and 60% in 1998 at ponds where pumping was being done. Mallards were selected as the indicator species to measure the effects of any treatability studies or remediation actions on ERF. Overall mallard mortality, calculated from telemetry and census data, decreased from 983 ducks in 1996 to 360 ducks in 1997, then increased to 532 ducks in 1998. The increase of mallard mortalities on ERF from 1997 to 1998 can be attributed to remediation efforts that caused more ducks to move from areas being treated to other contaminated areas not yet treated.

**Cummings, J.L., L. Clark, P.A. Pochop, and J.E. Davis** (1994) Eagle River Flats: A potential repellent for reducing waterfowl ingestion of white phosphorus. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado,* p. 3.

The U.S. Army has used the Eagle River Flats (ERF) on Fort Richardson (Alaska) as an artillery impact area since 1945. The 1000-ha salt marsh is a spring and fall staging area for migrating waterfowl. In August 1981, hunters discovered a large number of duck carcasses in the ERF. Since that time, the Army and other Federal and state agencies have been involved in identifying the cause of the waterfowl mortality problem. By 1991, it was concluded that unoxidized white phosphorus (WP) particles within the ERF sediment were causing waterfowl mortality. This concern has stimulated efforts toward the development of an effective repellent to reduce or eliminate waterfowl mortality caused from WP in ERF. This study evaluates a methyl anthranilate (MA) bead formulation in a simulated pond setting to determine the effects on mallard feeding behavior and mortality of mallards feeding in a WP contaminated area on ERF. The experiment was conducted between 0800 and 1600 hours for a 7-day pretreatment and a 10-day treatment period. The bead matrix was designed to settle to the bottom of the pool and only release MA when broken by feeding mallards. The bead formula was applied at 21.7 kg / ha or about 7 beads / $cm^2$ so that mallards would encounter it when feeding off the bottom. It was effective in reducing time mallards spent in pools ($p \leq 0.01$). The average number of minutes mallards spent in pools decreased to below pre-treatment levels. Field tests in a WP-contaminated area on ERF with the same formulation and application rate indicate that mortality to ducks continuously exposed to WP-contaminated sediment was about 60% lower in treated pens within the first 24 hours after treatment. At the conclusion of the test, 144 hours after treatment, mortality was 50% lower in treated pens. In a free-ranging situation, it is anticipated that the relative risk of poisoning in MA treated areas would decrease if ducks could leave the area.

**Gossweiler, W.A.** (1994) Eagle River Flats—An Army environmental rescue operation. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado,* p. 2.

The Eagle River Flats is a highly productive and complex wetland at the mouth of Eagle River, in Alaska's Cook Inlet. The entire wetland is contained within the Fort Richardson Army installation. Like other wetlands in the area, it serves as an important staging and feeding ground for thousands of waterfowl and shorebirds. The Eagle River Flats has also been used as the primary ordnance impact area on Fort Richardson since 1949. In the late summer of 1982, Army biologists discovered the remains of an unusually high number of dead waterfowl on the Flats. Convinced that a serious and chronic problem was present in the wetlands, the Army biologists enlisted the help of several governmental agencies. For over 10 years waterfowl carcasses were collected from the Flats and sent to various labs for analysis. The results were always the same, inconclusive. In May of 1990 CRREL was brought into the investigation because of their expertise with explosive compounds. With a little luck and a lot of hard work, CRREL, by the end of the 1990 field season, identified the agent responsible for the waterfowl mortality as white phosphorus, which is used in military smoke and marking rounds. With this discovery comes the overwhelming task of evaluating the human and ecological risks posed by this toxic material and trying to find effective methodologies for resolving or remediating the contamination problem.

**Gossweiler, W.A., C.M. Collins, and J.L. Gusmano** (1995) Fort Richardson multi-agency site investigation. In *Proceedings, 21st Environmental Symposium & Exhibition of American Defense Preparedness Association, 18–21 April, San Diego, California,* p. 331–343.

The Eagle River Flats (ERF) is an estuarine salt marsh in the northwest sector of Fort Richardson. Fort Richardson's 55,000 acres include a central cantonment area surrounded by ranges and impact and maneuver areas to the north, east, and south. The Municipality of Anchorage (MOA) and Elmendorf Air Force Base (AFB) lie west of Fort Richardson.

The ERF has been used as the primary ordnance impact area for Fort Richardson since the mid-1940s. The ERF is a 2165-acre wetland within Fort Richardson at the mouth of Eagle River, adjacent to Upper Cook Inlet. It is an important staging ground for several species of waterfowl, including ducks, geese, and swans, during spring and fall migrations. During the peak migration periods, the waterfowl population may total 3000 to 5000.

In 1980, U.S. Army biologist first noticed an unusually high number of waterfowl carcasses, including several dead swans, in the ERF marshes. Between 1982 and 1985, random ground searches were conducted at the ERF by the U.S. Army, the U.S. Fish and Wildlife Service (USFWS), and the Alaska Department of Fish and Game (ADFG). The discovery of abnormally high numbers of dead waterfowl during the searches indicated that a potentially serious problem existed. The dead and dying waterfowl were looked for and observed in several areas, including those referred to as Areas A, B, C, and D.

To approach the problem in an organized and scientific manner, an interagency task force was formed in 1987. The ERF Task Force was composed of representatives from the following Federal and state agencies: U.S. Army; U.S. Environmental Protection Agency (USEPA); U.S. Fish and Wildlife Service (USFWS); Alaska Department of Fish and Game (ADFG); and Alaska Department of Environmental Conservation (ADEC).

The primary objective of the ERF Task Force was to identify the cause of the waterfowl die-offs and recommend remedial alternatives. Since the formation of the ERF Task Force, several studies and investigations have been conducted to identify contaminants of concern, to characterize the nature and extent of contamination, and to evaluate potential remedial alternatives.

**Gustafson, M., R. Grove, E.F. Hill, and D.W. Sparling** (1994) Preliminary investigation on bioindicators of exposure to white phosphorus ($P_4$). In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November 1998, Denver, Colorado,* p. 3.

Although $P_4$ causes waterfowl mortality and may be transferred though food chains, it is quickly metabolized or eliminated from tissues and is not a persistent indicator of exposure in living organisms. This paper reports preliminary findings of the effects of $P_4$ on blood chemistry in an attempt to identify a reliable indicator of exposure to $P_4$. Adult mallards were gavaged with 3.4 mg $P_4$/kg body weight dissolved in corn oil ($LD_{20}$); half were given a single dose and half were given 2 doses spaced by 3 days. Controls were treated with corn oil only. Several parameters, including blood urea nitrogen (BUN), creatinine (CR), BUN/CR, $CO_2$, bilirubin, potassium, lactase dehydrogenase (LDH), and phosphorus, significantly increased between control and dosed birds. Hematocrit, serum globulins, and glucose decreased in dosed birds. Hematocrit and LDH also showed significant sex by dose interaction, with males responding more strongly than females. Many of these parameters and histopathology support the observation that sublethal exposure to $P_4$ causes liver damage in mallards. Discussion will focus on the use of these parameters in nondestructive diagnosis of $P_4$ exposure under field conditions.

**Henry, K.S., C.M. Collins, and C.H. Racine** (1995) Use of geosynthetics to prevent white phosphorus poisoning of waterfowl in Eagle River Flats, Alaska. In *Proceedings, Geosynthetics '95, February, Nashville, Tennessee,* p. 483–496.

Experiments were conducted to investigate the feasibility of using geosynthetics to keep waterfowl from eating white-phosphorus-contaminated pond sediments in an estuarine salt marsh. A laboratory study evaluated whether white phosphorus particles become suspended into overlying water because of 1) upward water flow through contaminated sediment capped (or not) with geotextile or 2) tapping of the top of the geotextile or sediment and then vigorously stirring the water to simulate waterfowl feeding and swimming. White phosphorus particles of a size that would be dangerous to waterfowl did not become suspended in the water column under any of the test conditions. A field study documented sedimentation and vegetation growth on three geotextiles and on an erosion control product placed on the bottom of salt marsh ponds. Means to vent gas formed in sediments through saturated material with pore diameters smaller than 3.4 mm is needed, as well as a way to anchor products in ponded areas subject to strong tidal action.

**Henry, K.S., and J.A. Stark** (1997) Geosynthetic barriers to prevent poisoning of waterfowl. In *Proceedings, XIVth International Conference on Soil Mechanics and Foundation Engineering, 6–12 September, Hamburg, Germany,* p. 1819–1822.

The feasibility of using geosynthetics to cover contaminated pond sediments and prevent waterfowl access to them was studied. Geosynthetic barriers were placed in ponds, the water above them was vigorously stirred, and the barriers were loaded by dropping a mass onto them to determine their ability to retain sediment below them and withstand damage. The barriers reduced the amount of sediments resuspended during stir and loading tests by a least 30%, and sustained no damage. Thus, they can probably prevent waterfowl from accessing and eating toxic particles contained in the sediment below them.

**Henry, K.S., M.R. Walsh, and S.T. Hunnewell** (1996) Testing and performance of silt fence for dredging operation. In *Proceedings, Geofilters 96, 29–31 May, Montreal, P.Q., Canada,* p. 491–500.

This study was designed to select a silt fence filter for contaminated dredging spoils. Candidate geotextiles were used in laboratory tests to filter particles suspended in water. The geotextile selected retained particles in the size range of interest in laboratory tests that simulated field conditions. The geotextile silt fence was installed in the field, and initial flow rates through it matched those predicted in the laboratory. Unfortunately, the silt fence was removed because it clogged, primarily because of unexpected high amounts of suspended sediment in the supernatant.

**Hull, J. H., J. M. Jersak, P. A. Pochop, and J.L. Cummings** (1998) Evaluating a new in-situ capping technology for mitigating contaminated sediments. In *Proceedings of the 15th World Dredging Congress, 28 June–2 July, Las Vegas, Nevada.* Vol. 1, p. 555–576.

Dredging and removal may be the most practical method for mitigating contaminated sediments in many situations. However, in some circumstances, dredging as a mitigative technique may be neither cost effective nor environmentally protective in light of the volume of sediments impacted, the potential for sediment resuspension during dredging, and potential impact to aquatic life and habitat during dredging and removal activities. The technique of in-situ sediment capping is being more often considered as a relatively non-intrusive and cost-effective alternative to dredging. Most in-situ capping projects involve the use of sand-sized sediments. Such coarser-grained materials may adequately isolate contaminated sediments physically, but do little to chemically attenuate sediment-borne contaminants. Such materials may also be more prone to erosional losses and redistribution. Summarized here are field-scale studies developed to test a new, clay mineral-based (composite aggregate) barrier technology for use in in-situ capping in wetland and riverine / estuarine environments—dynamic and contrasting ecosystems that offer a broad range of stressing factors for evaluating barrier effectiveness. Specifically, data are presented from one study indicating that this barrier is effective in isolating phosphorous-contaminated wetland sediments from Alaskan waterfowl populations. Also presented are methodologies and available laboratory results from another study in which this technology is being tested for isolating soft, fine-grained PCB-contaminated river sediments.

**Hunter, L.E., D.E. Lawson, S.E. Bigl, B.M. Nadeau, P.B. Weyrick, and J.H. Bodette** (1995) White phosphorus mobilization at the Eagle River Flats, Ft. Richardson, Alaska. In *Proceedings, Geological Society of America, Fairbanks, Alaska*, p. 27.

Eagle River Flats (ERF) is a subarctic estuary and salt marsh that has become the site of extensive environmental study due to the high mortality of migratory waterfowl during the 1980s and 1990s. Investigations by CRREL identified that small particles (~1 mm) of white phosphorus (WP; $P_4$), from artillery illumination rounds, ingested by waterfowl feeding from pond bottoms, was the cause of observed high mortality rates. Although the use of WP-bearing munitions was halted February 1990, ERF remains an active impact area and limited sections of the marshes and ponds retain high levels of WP contamination.

Investigations of physical system dynamics as part of the site assessment are to develop physical models of the depositional system and WP fate in the system, and to evaluate system response to remediation. Studies include sediment trapping, measuring water quality parameters and suspended sediment concentrations, monitoring tidal and river dynamics, measuring river and gully bank erosion, bathymetric mapping of Knik Arm near the mouth of Eagle River, and sampling for WP in ERF sediments and transport (water and ice). These studies have monitored WP in transport within the ERF system and indicate that it may be exiting through ice and river transport into the Knik Arm. Processes relevant to this paper are particulate resuspension of soft muddy pond substrates, gully erosion and transport, and ice freeze-on, plucking, and rafting of contaminated sediments.

Field studies indicate that physical system processes must be considered before remedial measures are taken. Rapid sedimentation rates in ponds (10–30 mm / yr) may provide natural remediation; however, gullies are eroding towards the most heavily contaminated ponds and may begin draining them in the next 15 to 50 years. Natural pond drainage may accelerate the natural decomposition of WP, if sediments can dry sufficiently. Rapid erosion may also release WP into gullies, making it available for natural transport and redistribution. Gully erosion may be accelerated by proposed dredging operations that alter surface morphology, drainage, and sediment characteristics. Capping of contaminated regions is also threatened by gully processes that can undermine remediated regions while ice processes can produce plucking or shoving capping materials and ripping of geotextiles.

**Hunter, L.E., D.E. Lawson, and S.R. Bigl** (1997) Recession of tidal creeks at Eagle River Flats, Fort Richardson, Alaska. In *Proceedings, Cook Inlet Symposium, Anchorage, Alaska*, p. 14.

Tidal creeks were monitored as part of the site characterization of Eagle River Flats (ERF), a subarctic salt marsh in Upper Cook Inlet. Physical system studies have characterized surface water quality, tidal dynamics, sedimentation, sediment transport, and tidal creek erosion to assess white phosphorus fate and transport, and to evaluate natural remediation. Aerial photographic analyses and recent monitoring indicate that tidal creek evolution is dynamic and important in controlling changes in the salt marsh ecosystem and surface hydrology. Rates of headward recession ranged from nearly negligible inland to >30 m / yr near the coast. Headward recession is often orders of magnitude larger than lateral recession, while the spatial relationship between recession types is similar on both sides of the Eagle River. Apparent controls on recession rates are the height of the flooding tidal prism, timing of spring flooding following thaw, surface vegetation, topography, buried peat horizons, and headwall distance from the Knik Arm or Eagle River. Headward recession of tidal creeks appears cyclic and linked to recurrent earthquake events. Recession rates increased following the 1964 earthquake, resulting in deeply incised tidal creeks that are the main water pathways during tidal flood and ebb. Tidal creek dynamics are capable of causing rapid changes in surface hydrology that can affect contaminant transport and decomposition.

**Nam, S.I., D.L. MacMillan, and B.D. Roebuck** (1994) Deposition and distribution of white phosphorus into chicken eggs. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado*, p. 3.

The thousands of waterfowl deaths occurring at Eagle River Flats, Anchorage, Alaska, have been attributed to the ingestion of unoxidized white phosphorus ($P_4$) particles. With the recognition of $P_4$ as the toxicant, numerous plans are being implemented to mitigate the contaminated areas. Methods are also in development to monitor the effectiveness of the cleanup process. One proposed method is to monitor herring gull eggs. It has been documented that the herring gulls in Eagle River Flats are consuming ducks from the contaminated areas and are directly exposed to $P_4$. So by collecting the eggs of the herring gulls, and assaying for $P_4$, one could assess the availability of $P_4$ in the area. However, before the implementation of this monitoring system, the transfer and distribution of $P_4$ in eggs needs to be explored. We dosed egg laying hens (*Gallus domesticus*) with 1 mg / kg or 3 mg / kg of $P_4$ and their eggs were collected and analyzed for $P_4$. The yolk and the white were separated and $P_4$ was extracted into isooctane and quantified by gas chromatography. For both doses, $P_4$ was detected predominately in the yolk 2 days after dosing. $P_4$ was detected until 6 days after dosing at 1 mg / kg and until 8 days for the higher dose. On the average, the total $P_4$ recovered in eggs was less than 0.01%.

**Nam, S.I., B.D. Roebuck, and M.E. Walsh** (1993) The role of phosphine in white phosphorus toxicity. In *Proceedings, SETAC 14th Annual Meeting, 14–18 November, Houston, Texas*, p. 252.

White phosphorus, $P_4$, has been implicated in thousands of waterfowl deaths in Eagle River Flats, Anchorage, Alaska. Lethality, however, could not be correlated with the level of $P_4$ found in the gizzard, nor in the fatty tissues of these ducks. It has been hypothesized that the toxicity of $P_4$ may be attributable to its metabolites rather than the parent compound. In vitro studies were undertaken to determine if phosphine ($PH_3$), a toxic gas, was generated from $P_4$ by various rat tissues. Liver and small intestine tissues and cecum contents of the gastrointestinal tract of the F344 rat were used. Tissue homogenates were made with 0.3 M Tris (pH 7.4) and placed in 40-mL vials. One set of samples was boiled for 10 minutes to denature enzymes and microbes. Samples were incubated in a 37°C water bath prior to and subsequent to the addition of $P_4$ (1 mg). Phosphine was determined and quantified by GC at times up to 2 hours after $P_4$ exposure. By 2 hours, all samples produced phosphine close to toxic concentrations (3–65 ppm). $PH_3$ concentrations in boiled and non-boiled samples were similar, thus indicating that the formation of $PH_3$ from $P_4$ may be a nonenzymatic reaction. Furthermore, the toxicity of $P_4$-exposed waterfowl may be ascribable to $PH_3$ rather than $P_4$.

**Nam, S.I., B.D. Roebuck, M.E. Walsh, and C.H. Racine** (1992) Biotransfer and accumulation of white phosphorus. In *Proceedings, SETAC 13th Annual Meeting, 8–12 November, Cincinnati, Ohio.*

Eagle River Flats, a marsh located near Anchorage, Alaska, has been the site of thousands of waterfowl deaths since 1980. Unoxidized white phosphorus ($P_4$) particles are found in the marsh sediments. Ingestion of $P_4$ is the primary cause of the waterfowl deaths. In poisoned ducks, the gizzards contained mg amounts of $P_4$; the tissues had microgram amounts of $P_4$. Studies were undertaken to determine if predators of ducks were exposed to $P_4$. Field observations were made to determine predators and frequency of predation. Tissue $P_4$ was extracted into isooctane and quantified by gas chromatography. Numerous predation events were directly observed. All ducks found sick or dead at the site contained $P_4$. Predators of waterfowl included bald eagles, herring gulls, and ravens. Tissues from a dead immature female bald eagle contained $P_4$: 0.060 µg/g of tissue in the fat and 0.010 µg/g tissue in the skin. Two collected herring gull eggs contained traces of $P_4$. Biotransfer of $P_4$ from meat to predator has been confirmed and quantified in the laboratory using kestrels. Based upon the frequently observed events of predation and the lipophilic nature of $P_4$, the probability of $P_4$ poisoning to predators of ducks containing $P_4$ is great.

**Pochop, P.A., and J.L. Cummings** (1994) Laboratory and field evaluation of AquaBlok® to reduce mortality of foraging waterfowl at Eagle River Flats, Fort Richardson, Alaska. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado,* p. 3.

Eagle River Flats is an artillery impact area and is also an important spring and fall waterfowl staging area. However, white phosphorus, deposited in the sediment by certain types of explosives, has been found to cause mortality of large numbers of foraging waterfowl on Eagle River Flats. This study evaluated the effectiveness of AquaBlok® barrier system as a physical barrier to foraging waterfowl. A laboratory trial was conducted to evaluate the physical characteristics, application rate, and longevity of AquaBlok® when applied to bottom sediment in a simulated pond setting. The laboratory trial indicated that the AquaBlok® appeared to maintain its structure under mallard *(Anas platyrhynchos)* use. The field trial was conducted at Eagle River Flats, Fort Richardson, Alaska. Six mallards each were placed in a control ($7 \times 20$ m) and treated ($7 \times 7$ m) pen for a pre- and post-treatment period. During a 6-day pre-treatment period, all of the ducks died in the control and half of the ducks died in the AquaBlok® pen. After treatment, all of the control ducks and none of the AquaBlok® ducks died. Inspections of the AquaBlok® 42 days after application indicated that algae had begun to grow on it. A large scale field test is warranted to determine the feasibility of using AquaBlok® as an interim remediation action on Eagle River Flats to reduce waterfowl mortality caused by white phosphorus.

**Pochop, P.A., J.L. Cummings, C.A. Yoder, and W.A. Gossweiler** (in press) A physical barrier to reduce white phosphorus mortalities of foraging waterfowl. In *Journal of Environmental Engineering.*

White phosphorus has been identified as the cause of mortality to certain species of waterfowl using Eagle River Flats, a tidal marsh in Alaska that is an ordnance impact area belonging to the U.S. Army. A blend of calcium bentonite/organoclays, gravel, and binding polymers was tested for effectiveness as a barrier to reduce duck foraging and mortality. Following the application of the barrier to one of two contaminated ponds, we observed greater duck foraging and higher mortality in the untreated pond and no mortality in the treated pond after a year of tidal inundations and ice effects. Emergent vegetation recovered within a year of treatment. White phosphorus levels in the barrier were less than the method limit of detection, indicating no migration of white phosphorus into the material. Barrier thickness remained relatively stable over a period of 4 years, while vegetation was found to be important in stabilizing the barrier material.

**Racine, C.H., and L.E. Hunter** (1997) Ecology of salt marsh ponds at Eagle River Flats, Upper Cook Inlet, Alaska. In *Proceedings, Cook Inlet Symposium, Anchorage, Alaska,* p. 23.

White phosphorus contamination of several shallow ponds at Eagle River Flats initiated an evaluation of their physical, chemical, and biologic characteristics. Biological attributes (waterbirds, seeds, invertebrates, and vegetation) were measured along with physical characteristics (morphology and distribution, flooding dynamics, water quality). Three types of ponds were recognized (wet swales, permanent ponds, and intermittent ponds), each with different species and physical characteristics. Intermittent ponds and wet swales fill when tidal flooding is above a critical threshold. The same ponds dry out during prolonged intervals between flooding events. Permanent ponds receive fresh water from upland springs, nearby rivers and creeks, and precipitation, while brackish water is introduced during tidal flooding. Shorebirds use intermittent ponds with high populations of bloodworms (*Chironomus salinarius*), while dabbling ducks and swans use deeper permanent ponds with abundant seeds and other invertebrates. The history of these ponds appears closely tied to process adjustments following earthquakes, controlling cycles in tidal creek development, and sedimentation. This baseline pond information should help direct future restoration of ponds following dredging, draining, or covering with a bottom barrier.

**Racine, C.H., M.E. Walsh, C.M. Collins, L. Reitsma, and B. Steele** (1993) Sampling and site assessment of white phosphorus sediment contamination in ponds of an Alaskan salt marsh. In *Proceedings, SETAC 14th Annual Meeting, 14–18 November, Houston, Texas*, p. 117.

The 865-ha Eagle River Flats is an estuarine salt marsh on Cook Inlet near Anchorage where artillery training since the 1940's has resulted in the contamination of shallow pond sediments with the smoke-producing munition, white phosphorus ($P_4$). Ingestion of small white phosphorus particles by migrating waterfowl, feeding in the pond bottom sediments, has resulted in an annual mortality of over 1000 waterfowl. There are literally hundreds of ponds of various sizes and shapes and the determination or site assessment of which ponds are contaminated presented a large and difficult sampling problem. To facilitate this work, we developed an integrated plan linking sediment sampling of ponds with waterfowl and predator observations, carcass counts and remote sensing-GIS mapping techniques. The success of using these various techniques and "indicators" to determine which ponds are contaminated is described.

**Racine, C.H., M.E. Walsh, C.M. Collins, B.D. Roebuck, and W. Gossweiler** (1991) Waterfowl mortality in Eagle River Flats impact area, Anchorage, Alaska. In *Proceedings, 15th Annual Army Environmental R&D Symposium, June, Williamsburg, Virginia*, p. 563–575.

The deaths of hundreds of migrating dabbling ducks and 10–50 swans have been documented yearly for the last 10 years in Eagle River Flats (ERF), an estuarine salt marsh on Ft. Richardson, Alaska. This marsh has been used for the past 40 years as an artillery impact range by the U.S. Army. During May and August 1990, CRREL collected over 250 sediment and water samples and analyzed them for munitions residues. We found 2,4-DNT in a limited area of ERF not used by waterfowl and white phosphorus in sediments from the bottom of shallow ponds where waterfowl feed. Tissues from waterfowl observed to die or found dead in the salt marsh were collected, and we found white phosphorus in the gizzards of all 19 carcasses collected in Eagle River Flats. Adult mallards dosed in the laboratory with white phosphorus showed identical behavioral symptoms to those of wild ducks observed to become sick and die in Eagle River Flats. All evidence indicates that white phosphorus, as a particulate in the sediments, is responsible for the death of waterfowl in Eagle River Flats. Since the bottom sediments of the shallow salt marsh ponds are anaerobic, the white phosphorus particles will persist in the sediments indefinitely and remain a threat to waterfowl.

**Racine, C.H., M.E. Walsh, C.M. Collins, and S. Taylor** (1992) White phosphorus poisoning of waterfowl in a wetland impact area. In *Proceedings, Smoke/Obscurants Symposium XVI, 14–16 April, Laurel, Maryland*, p. 787.

White phosphorus is the cause of death of thousands of waterfowl each year at Eagle River Flats (ERF), the impact area for artillery training at Ft. Richardson, Alaska. We have isolated white phosphorus particles from ERF sediments with lengths (maximum cross-sectional diameters) ranging from 0.26 to 2.9 mm. Sediment-sieving waterfowl such as dabbling ducks and swans ingest these particles that are in the size range of food items, such as seeds and invertebrates. Since a lethal dose of white phosphorus is on the order of 1 mg/kg of body weight, the ingestion of a single particle can be fatal to a small duck. These white phosphorus particles were deposited from smoke rounds fired into this wetland. Burning white phosphorus extinguishes when immersed in water, leaving a significant amount of unreacted material in the burn residue. Once deposited, the anaerobic sediments prevent oxidation, thereby preserving the white phosphorus indefinitely.

**Racine, C.H., M.E. Walsh, B.D. Roebuck, and C.M. Collins** (1991) Elemental phosphorus as the cause of waterfowl mortality in a salt marsh at Ft. Richardson, Alaska. In *Proceedings, 83rd Annual Meeting, American Society of Agronomy, 27 October–1 November, Denver, Colorado*, p. A–3.

The yearly death of 1000–2000 migrating dabbling ducks (*Anas* sp.) and 10–50 swans (*Cygnus* sp.) has been documented for the last 10 years in Eagle River Flats, an estuarine salt marsh near Anchorage, Alaska. This marsh has been used over the past four decades for artillery training by the U.S. Army. The evidence presented here strongly supports the hypothesis that feeding waterfowl are ingesting small particles of the highly toxic incendiary munition, white phosphorus ($P_4$), stored in the bottom anoxic sediments of shallow salt marsh ponds. Farm-reared mallards dosed with $P_4$ showed nearly identical behavioral symptoms to those of wild ducks that became sick in Eagle River Flats. White phosphorus does not occur in nature but was found in both the sediments where dabbling ducks and swans feed and in the gizzards of all 20 waterfowl carcasses collected in Eagle River Flats.

**Rattner, B.A., and J.D. Walker** (1994) Designation of white phosphorus for toxicity testing by the TSCA Interagency Testing Committee. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado*, p. 4.

Approximately 700 million pounds of white phosphorus ($P_4$) are produced annually for various uses, including smoke-producing munitions. Thousands of ducks and other wildlife have been poisoned by ingestion of particulate $P_4$ at a wetland artillery impact area in Eagle River Flats, Alaska. Although $P_4$ has been detected at several military installations, the extent of contamination in the U.S. remains largely unknown. The Toxic Substances Control Act Interagency Testing Committee (TSCA ITC) reviewed published findings, study results submitted under TSCA sections 8(d) and 8(e), and ongoing research activities, relating to $P_4$ exposure, chemical fate, and ecological and health effects. In view of potential widespread $P_4$ pollution of wetlands, and the need for hazard data for amphibians, reptiles, and furbearers frequenting these habitats, the ITC designated $P_4$ for acute toxicity testing in its 34th report. The paucity of data on $P_4$ bioconcentration and food chain transport by plants, and the herbivorous nature of many species, will also necessitate aquatic plant toxicity and terrestrial plant uptake and translocation test data. Chronic exposure and reproductive studies may be designated pending review of data. Through the efforts of the ITC, the U.S. EPA and Department of the Interior will obtain data to assist in its risk assessment of $P_4$ to wildlife and their supporting habitat.

**Roebuck, B.D., and S.I. Nam** (1995) Toxicological properties of white phosphorus ($P_4$): Effects of particle size. In *Proceedings, SETAC 16th Annual Meeting and Second SETAC World Congress, 6–9 November, Vancouver, B.C*, p. 136.

The ingestion of particles of white phosphorus ($P_4$) causes mortality of waterfowl at Eagle River Flats, Alaska. $P_4$ poisoning results in behaviors that attract predators. Residual $P_4$ presents risk to predators and scavengers. To date, the toxic properties of $P_4$ have been characterized when $P_4$ is dissolved in various digestible oils. Herein, we compare the properties of dissolved $P_4$ to particulate $P_4$. Farm-reared mallards *(Anas platyrhynchos)* were gavaged with $P_4$ (12 mg/kg body weight) dissolved in oil or as either large particles (1.87-mm mean diameter) or small particles (0.95-mm diameter). Signs of intoxication and times to convulsion were monitored. Individuals were autopsied at the onset of convulsions. $P_4$ in digestive tracts and body fat was analyzed by gas chromatography. For all three treatments, the behaviors of ducks with $P_4$ intoxication were similar to observations of wild ducks. There was no difference between treatments for onset of lethargy, vomiting, poor motor or muscle control, or the first convulsive event. At autopsy, $P_4$ was found throughout the digestive tracts with residual quantities of approximately 20% or less of the dose. Very little of the dissolved $P_4$ remained in gizzards, whereas in the small and large particle groups, the gizzard contents contained 78% and 64%, respectively, of the total $P_4$, within the digestive tracts. Tissue concentrations of $P_4$ were small and did not appear to be a significant source of $P_4$ to predators. In conclusion, intoxication from particles of $P_4$ is largely not a function of the size of the particles, but rather the dose. Residual $P_4$ in the digestive tracts represents a risk to secondary receptors. These relative risks of particulate $P_4$ to tissue $P_4$ are somewhat similar to poisoning from lead shot.

**Sparling, D.W.** (1995) Secondary toxicity in raptors caused by white phosphorus. In *Proceedings, SETAC 16th Annual Meeting and Second SETAC World Congress, 6–9 November, Vancouver, B.C,* p. 140.

White phosphorus (WP) has caused waterfowl die-offs in a tidal salt marsh used by the U.S. Army for artillery practice for more than 40 years. Bald (*Haliaeetus leucocephalus*) and golden (*Aquila chrysaetos*) eagles have been observed feeding on dead and dying waterfowl on the marsh and may be exposed to WP through ingestion of contaminated birds. One carcass of each eagle species has been found with measurable levels of WP in fat. To determine if raptors can become intoxicated by ingesting prey that have been exposed to WP, we fed live, 10-day-old white leghorn chicks three sublethal doses of WP. We euthanized the chicks 6 hours after the last dose and separated them into two groups—one with the digestive system from gizzard anteriorly removed (NoGut) and one with the digestive system intact and a 1.1-mg pellet of WP implanted deep into the crop (Pel). A third group of same-aged chicks unexposed to WP was used for controls. Fifteen kestrels (*Falco sparverius*) were randomly assigned to each of the treatments and 10 to the control diet. By 7 days of the study, eight of the kestrels had died on the Pel and three on the NoGut diet. Survivors on the Pel diet had significantly lower hematocrit, hemoglobin, and final body weights, and greater liver/body weight ratios and weight loss than control birds. The study showed that raptors and possibly other predators are at risk both when consuming the flesh of prey that have succumbed to WP poisoning and when ingesting WP pellets that are incorporated in body parts but that the risk is greater when pellets are present.

**Sparling, D.W., M. Gustafson, E.F. Hill, P. Klein, and R. Grove** (1994) Acute toxicity of white phosphorus ($P_4$) in game farm mallards. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado,* p. 2.

Extensive waterfowl mortality from ingested particles of $P_4$ has occurred at Eagle River Flats, Fort Richardson, Alaska, for several years. Very little is known about the pathology of $P_4$ in avian species. This paper reports on the acute toxicity and physiological effects of $P_4$ in mallards. Adult mallards were orally gavaged with a single dose of $P_4$ dissolved in corn oil in the 2.0- to 9.1-mg/kg range. The $LD_{50}$ for adult males was calculated as 6.5 mg $P_4$/kg body weight (95% C.I. = 5.8–6.9 mg/kg, percent mortality = –6.089 ± 0.953, dose, S.E. on slope = 0.330). Adult females were less sensitive than adult males, as only 25% died at each of the four highest doses. In another test, juvenile male and female mallards were as sensitive as adult males. Clinical signs of exposure included lethargy, tremors, rhythmic head weaving, and convulsions and were consistent with cellular anoxia. Some birds that survived acute exposure died after 2–3 days from liver and kidney degeneration. Liver/body weight ratios increased, brain and plasma ChE levels decreased, and hematocrit and hemoglobin were depressed after exposure, depending on the sex and age of the bird. Levels of $P_4$ in fat, skin, and liver were not consistent with exposure levels. Clinical signs, gross histopathology, and $P_4$ concentrations in tissues were similar to those of birds dying from $P_4$ toxicity in the field.

**Walsh, M.E., C.M. Collins, R.N. Bailey, and C.L. Grant** (1997) Composite sampling of white phosphorus contaminated sediments. In *Proceedings, SETAC 18th Annual Meeting, 16–20 November, San Francisco, California,* p. 92.

At contaminated sites undergoing remediation, cleanup decisions are frequently based on the contaminant concentrations found in soils. Concentration estimates are obtained using standard analytical methods, which assume a homogeneous sample that is representative of the site. However, obtaining a representative sample of a heterogeneous soil or sediment is a challenge. One very difficult contaminant to characterize in the environment is white phosphorus from exploded munitions. Spatial heterogeneity of concentration estimates is extreme, varying over many orders of magnitude for closely spaced discrete samples. To provide cost-effective data upon which decisions may be made, composite sampling methods were designed to aid in site characterization and remedial process monitoring of a white phosphorus contaminated area. Closely spaced discrete samples were collected on a grid pattern and pooled to form composites. The composites were then divided by size fractions. Mean white phosphorus concentrations were estimated for the fine-grained size fraction that was obtained by suspension with water. The presence of highly toxic solid white phosphorus particles, the form that may be ingested by feeding waterfowl, was determined in the coarse-grain size fraction that was obtained by sieving.

**Walsh, M.E., C.M. Collins, and C.H. Racine** (1994) The effect of sediment moisture and temperature on the persistence of white phosphorus particles. In *Proceedings, SETAC 15th Annual Meeting, 30 October–3 November, Denver, Colorado,* p. 3.

Eagle River Flats, Fort Richardson, Alaska, is the first Army training area identified with white phosphorus contamination, and recent surveys at other army training areas have revealed white phosphorus contamination. Previous to our findings at Eagle River Flats, white phosphorus was thought to be non-persistent in the environment, indicating that the current understanding of the environmental fate of white phosphorus is poor. Much of the basic research on the chemistry of white phosphorus was conducted prior to 1950 and was not concerned with environmental fate. Lack of understanding of the environmental fate and transport of white phosphorus residues precludes accurate ecological assessments and efficient cleanup. Remedial techniques currently under investigation at Eagle River Flats (ERF) include dredging, covering, and pond draining, all of which involve changing the salt marsh habitat. Limitation of remedial actions to those areas where WP is persistent and will continue to threaten wildlife would make the remedial process more efficient and less controversial. Studies were conducted on the persistence of white phosphorus residues in sediment. Specifically, the effect of sediment moisture and temperature on the persistence of white phosphorus particles was investigated under laboratory and field conditions.

**Walsh, M.E., C.H. Racine, C.M. Collins, and B. Nadeau** (1993) Factors that determine persistence of white phosphorus residues in a wetland impact area. In *Proceedings, SETAC 14th Annual Meeting, 14–18 November, Houston, Texas*, p. 265.

Eagle River Flats is an estuarine salt marsh on Cook Inlet, Alaska. Since the 1940s, the marsh has been used by the Army as an impact area for artillery training. Training with white phosphorus ($P_4$), a smoke-producing munition, has resulted in contamination of the sediments of shallow ponds in Eagle River Flats. Thousands of waterfowl die each year at Eagle River Flats after feeding in these ponds. Evidence will be presented that the $P_4$ is in particulate form in the sediments, and that the particles are similar in size to seeds and invertebrates ingested by waterfowl and to grit used by waterfowl. Factors that determine the persistence of these particles include sediment porosity, moisture content, and temperature. These factors interact to determine the rate at which the $P_4$ particles sublime to form $P_4$ vapor. Previous models and studies of $P_4$ persistence in soil have focused on the availability of oxygen. Oxidation of $P_4$ is a vapor phase reaction, thus sublimation must precede oxidation. While oxygen is important in the detoxification of $P_4$, the principal mechanism determining the persistence of $P_4$ particles is the rate at which the $P_4$ sublimes. Oxygen may actually slow sublimation by the formation of oxidation products around the $P_4$ particles that impose a diffusion barrier to $P_4$ vapor.

**Walsh, M.E., S. Taylor, D. Anderson, and H. McCarty** (1995) Analytical methods for white phosphorus ($P_4$) in sediment and water. In *Proceedings, 11th Annual Waste Testing & Quality Assurance Symposium, 23–28 July, Washington D.C.*, p. 380–387.

White phosphorus ($P_4$) can produce severe adverse ecological impacts if released into environment. First produced in the United States over 100 years ago for use in matches, and subsequently for rat poisons and fireworks, today it is primarily used in the production of phosphoric acid and as a smoke-producing munition. To date, there is no standard analytical method for white phosphorus in environmental matrices. We have been using an analytical method based on solvent extraction and gas chromatography to determine white phosphorus in sediments and water from an Army training area. For sediments, a method detection limit of less than 1 µg/kg was achieved for white phosphorus extracted with isooctane and determined with a portable capillary gas chromatograph equipped with a nitrogen-phosphorus detector. For water, extraction with isooctane may be used to determine concentrations greater than 0.1 µg/L. However, to meet water quality criteria for aquatic organisms, preconcentration of the solvent extract is required. Owing to the relatively high vapor pressure of white phosphorus, a nonevaporative preconcentration step is used. $P_4$ is extracted from water using diethyl ether (10:1 water:solvent ratio). The ether phase is collected, then reduced in volume by shaking with reagent-grade water. By using the appropriate volume of water, excess ether is dissolved away, resulting in a preconcentration factor of 500 while heat is avoided and loss of $P_4$ by volatilization minimized. Using this preconcentration procedure, a method detection limit of less than 0.01 µg/L was achieved.

To minimize use of solvent in the laboratory, solid phase microextraction (SPME) may be used to screen samples for contamination. Exposure of a 100-µm polydimethylsiloxane phase to the headspace above a sediment or water sample for 5 minutes, followed by thermal desorption in the injection port of the gas chromatograph, provides sensitivity similar to that obtained by solvent extraction. Since this method is based on equilibrium partitioning between the sample, headspace, and solid phase, response is matrix-specific. Work is in progress on calibrating this procedure for quantitative analyses.

This analytical method will be proposed for inclusion in SW–846 Update III as Method 7580: White Phosphorus by Solvent Extraction and Gas Chromatography.

**Walsh, M.E., S. Taylor, B.D. Roebuck, and S.I. Nam** (1995) Analytical methods for white phosphorus. In *Proceedings, SETAC 16th Annual Meeting and Second SETAC World Congress, 6–9 November, Vancouver, B.C*, p. 337.

There is no standard analytical method for white phosphorus ($P_4$) in environmental matrices. To determine white phosphorus in sediments, water, and animal tissues, we are using an analytical method based on solvent extraction and gas chromatography with a nitrogen-phosphorus detector. For sediments and tissues, method detection limits (MDL) of less than 1 and 10 µg / g, respectively, were achieved by extraction with iso-octane. For water, pre-concentration of the solvent extract is required to detect $P_4$ at the water quality criteria for protection of aquatic organisms (0.01 µg / L). Because of the high vapor pressure of $P_4$, a non-evaporative pre-concentration step is used. $P_4$ is extracted using diethyl ether (10:1 water:solvent). The ether phase is collected, then reduced in volume by shaking with reagent-grade water to dissolve excess ether. A pre-concentration factor of 1000 is obtained without heat, minimizing loss of $P_4$, by volatilization. Using this pre-concentration procedure, an MDL of less than 0.01 µg / L was achieved. To minimize use of solvents, solid phase microextraction (SPME) may be used to screen samples for $P_4$. Exposure of a 100 µm polydimethylsiloxane phase to the headspace above sediment, water, or tissue samples for 5 minutes, followed by thermal desorption in the injection port of the gas chromatograph, provides sensitivity similar to that obtained by solvent extraction. Since this method is based on equilibrium partitioning between the sample, headspace, and solid phase, response is matrix specific. The analytical method for sediment and water will be proposed for inclusion in the EPA Office of Solid Waste SW–846 Update III as Method 7580: White Phosphorus by Solvent Extraction and Gas Chromatography.

**Walsh, M.R.** (1996) Dredging Eagle River Flats: Remediation study in an active impact area. In *Proceedings, 1996 UXO (Unexploded Ordnance) Forum, U.S. Department of Defense Explosives Safety Board, 26–28 March, Williamsburg, Virginia*, p. 266–274.

Remediation in closed impact areas is hazardous because of the presence of unexploded ordnance (UXOs). The problems with remediation of active impact areas are compounded by the infusion of fresh UXOs. At Eagle River Flats, Alaska, massive waterfowl die-offs at the Army's impact area triggered an investigation of the causes of mortality. With the discovery of white phosphorus from smoke rounds as the causal agent, a large, unprecedented multifaceted remedial investigation was initiated. Studies at the Flats can be categorized as either ecological assessments or remedial investigations. Ecological assessments considered the physical and biological dynamics of the Flats and the impact of these factors on the presence of white phosphorus and vice versa. Remedial investigations centered around either removal for treatment in a controlled environment or in-situ remediation or burial. Dredging is included in the first category. The objective of the experimental dredging project at Eagle River Flats is the removal of white-phosphorus-contaminated sediments from the Flats for treatment. The presence of UXOs and the quality of the environment are complicating factors. Dredging is selectively applied to those limited areas where white phosphorus is found, and conducted in such a manner as to minimize the environmental impact both while dredging and in the event of the detonation of a UXO. Specialized equipment obviously is needed to carry out this task. A small augerhead dredge was modified for remote control operation, using video feedback to the shore-based operator. The operator is stationed on shore in a hardened shelter that was tested by detonating a 105-mm HE round 35 m from the cab. Hydraulic fluid is vegetable based and nontoxic to prevent unacceptable pollution in case of spillage. Spoils from the dredging operation are pumped to a specially designed retention basin located on the nearby explosive ordnance disposal pad. The retention basin is used to decant supernatant from the spoils for eventual remediation of the sediment. For effective remediation and to lower the risk of a UXO detonating in the pump or along the spoils line, a method of excluding UXOs from the spoils stream is needed. After experimenting with several exclusion methods, we devised a cutter and grate system for the augerhead that successfully excluded UXOs while effectively processing sediment and vegetation. This work was successful enough that the remediation study for this superfund site has been moved to a removal action. The work is scheduled to be turned over to a private contractor for the 1996 deployment.

**Walsh, M.R.** (1996) Dredging in an impact area on Eagle River Flats, Ft. Richardson, Alaska. In *Proceedings, AMREM '96 Conference, 27–31 May, Albuquerque, New Mexico*, p. 401.

Eagle River Flats is an estuarine salt marsh located on Ft. Richardson, Alaska. For nearly 50 years, it has been an impact area for the Army and Air Force. In 1982, large, unexplained die-offs of waterfowl were documented, leading to several years of research into the cause of this recurring problem. In 1990, researchers from CRREL, in conjunction with the Ft. Richardson Environmental Resources Branch, Directorate of Public Works (DPW), discovered the cause of mortality: white phosphorus. After extensive study of the characteristics of white phosphorus ($P_4$) and the environment of the Flats, three remediation strategies were earmarked for further study: Covering contaminated areas with either geotextiles or bentonite; draining and exposing contaminated areas, allowing natural remediation; and dredging contaminated sediments for later treatment. This paper discusses the work done to date on dredging.

The presence of unexploded ordnance (UXOs) at Eagle River Flats (ERF) and the necessity to disrupt the environment at a minimal level posed serious dredge system design problems. Additionally, the only easily accessible storage and treatment area for the dredge spoils is located on the explosive ordnance disposal (EOD) pad, a RCRA (*Resource Recovery and Conservation Act*) site. The project was therefore initially divided into two design efforts: the spoils retention and treatment basin and the design of an appropriate dredging system. This work was accomplished in cooperation with the Alaska District, Corps of Engineers, and the Ft. Richardson DPW, with input from the Waterways Experiment Station.

The dredging system utilizes a small, remotely controlled augerhead dredge. The minimum distance from the dredge to the control cab, a hardened, mobile structure, is 40 m. The genset used to power the dredge is shore based, thus minimizing impact in case of a UXO detonation. Other design features include the use of a biodegradable vegetable-based hydraulic oil; locating primary systems, such as the slurry pump and power pack, as far from the dredgehead as feasible; and a cable traverse system to reduce penetrating UXO-laden sediments. An RF transmitter / receiver system transmits video information and sensor data to the shore-based operator. Several strategies were tried for dealing with the UXOs, all with the common goal of excluding the objects from the slurry pump and leaving them behind. The most effective method was a cutter-and-grate system incorporated into the dredgehead, which excludes the UXOs from entering the pump intake line without clogging the grate with vegetation.

The retention basin is a 0.8-ha structure built into the EOD Pad. Some existing material was used, but the presence of UXOs within the pad precluded complete construction with native materials. The base structure is constructed of consolidated gravel with 2-m-high berms. The interior is lined with a peaty-silt material to reduce the hydraulic conductivity to below $10^{-5}$ cm / s, acceptable for capping hazardous waste sites. Extensive testing by CRREL verified the liner performance. Two 3-m-square concrete splash pads were installed in the basin to check erosion from incoming spoils, and a drop inlet structure and weir was installed in one corner for controlled supernatant decantation. Instrumentation was installed to monitor sediment characteristics for remediation performance. Computer models indicated acceptable system performance.

System performance indicates that dredging is a viable option for consideration as a remediation strategy for Eagle River Flats. The grate system has allowed dredging to occur while minimizing the problems associated with UXO ingestion. Treatment studies of the $P_4$ contaminated retention basin sediments have begun, with definitive results anticipated for next season.

**Walsh, M.R.** (1997) Dredge removal of phosphorus-contaminated sediments at Eagle River Flats, Alaska. In *Proceedings, 5th International Symposium on Cold Region Development, American Society of Civil Engineers, 4–10 May, Anchorage, Alaska*, p. 139–142.

Eagle River Flats is an estuarine salt marsh located on Ft. Richardson near Anchorage, Alaska. For 50 years, it has been used as an impact area by both the Army and Air Force. During the 1980s, hundreds of dead and dying waterfowl were found in this area during the spring and fall migrations. For 5 years, various state and Federal agencies tried without success to unravel the mystery of this high mortality. Finally, in the spring of 1990, a group of researchers from CRREL, working in conjunction with the Ft. Richardson Directorate of Public Works, Environmental Branch (DPW-EV), discovered the cause of these massive die-offs: white phosphorus in the sediments of ponded areas.

Dredging is one of several remediation options currently being considered for the Flats. The dredge is best suited for areas that are permanently ponded and thus not conducive to the natural attenuation of the contaminant. The Flats are part of the Ft. Richardson Superfund site, and this work was performed in accordance with the U.S. Government *Comprehensive Environmental Response, Compensation, and Liability Act*. The primary sponsor is the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland. Support was provided by the U.S. Army Corps of Engineers, Alaska District, and U.S. Army Alaska (DPW-EV).

**Walsh, M.R., C.M. Collins, and M.E. Walsh** (1997) Remediation of white phosphorus contamination in wetlands using small scale dredging. In *Proceedings, SETAC 18th Annual Meeting, 16–20 November, San Francisco, California,* p. 124.

Deposition of white phosphorus (WP) in the saturated soils of the Eagle River Flats Firing Range on Ft. Richardson, Alaska, has resulted in dabbling waterfowl die-offs. Deaths through uptake of the contaminant continue, even though firing of WP rounds was discontinued in 1990. The persistence of WP in the cool, saturated sediments of permanently ponded areas on the range indicates that, unless addressed in means other than natural attenuation, the die-offs will continue for many years. Several remediation strategies have been demonstrated at this unique site, one of which is small-scale dredging with a remotely piloted system.

A specialized remote control augerhead dredge system was fabricated for the remediation project using standard equipment. An exclusion device was adapted to the augerhead to prevent ingestion of unexploded ordnance. Dredge spoils are pumped to a containment area where supernatant is decanted from the sediments. The contaminated sediments are then allowed to partially dry, after which sublimation of the contaminant occurs when the proper sediment dryness and temperature are reached. The spoils, sediment, and areas dredged are all sampled for analysis to assess effectiveness of the remediation strategy. An ongoing study of the attenuation process in the containment area is being conducted to determine if this treatment strategy is valid.

Three years of operation, including one by a contractor, indicate that dredging can be an effective means to address permanently ponded contaminated sites. Cost effectiveness in this application using the pilot system developed may be problematic.

**Walsh, M.R., M.E. Walsh, and C.M. Collins** (1998) In-situ remediation of white phosphorus in wetlands. In *Proceedings, American Society of Civil Engineer—Wetlands Engineering & River Restoration Conference 1998, 22–27 March, Denver, Colorado,* p. 116.

White phosphorus has been found to be the causal agent for massive waterfowl die-offs at the Eagle River Flats impact range on Ft. Richardson, Alaska. Research indicates that in-situ remediation of white phosphorus is possible if the sediments in which the contaminant persists can be desaturated and the temperature rises to where sublimation can occur. Several remediation methods have been studied at the Flats, the most promising of which is the pumped removal of ponded water using an automatic remote pumping system developed byCRREL. This paper will describe the system, its deployment, and the results of the first year's study.

---

## CONTRACT REPORTS

**Bouwkamp, C.A.** (1994) Contaminant inventory. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 87–110.

Sediment and water samples were collected from 18 sites in ponds and distributaries. Water samples were obtained from two locations in Eagle River. These samples were analyzed for WP, explosives, nutrients, target analytes, and target compounds. In addition, the water was field tested for temperature, dissolved oxygen, pH, oxygen-reduction potential, conductivity, and salinity. WP was the only contaminant compound found in ERF.

**Bouwkamp, C.A.** (1994) Food chain invertebrates and fish: Sediment bioassay. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 241–257.

Sediment samples were collected from 21 sites, and benthic invertebrates were isolated and identified. Four of these sites were contaminated with WP. There was only weak evidence of WP affecting the numbers of macroinvertebrates and no evidence that it affected species that were present or species diversity. No WP was found in the stickleback fish tissue of individuals living in the ponded areas of ERF; the low levels of WP found in the same water samples of the ponded areas would be diluted far beyond the recommended safe concentration of 0.01 µg/L when the flood tides bring new water into these ponds. The data from this study suggest that a WP cleanup level would not be driven by the effects on benthic macroinvertebrates or bioaccumulation in fish tissue.

In a laboratory sediment toxicity or bioassay test, all test organisms (the amphipod *Hyallela azteca* and the midge larva *Chironomus riparius)* died in contaminated ERF pond sediment even at the 20% sediment dilution level. This is attributed to very high WP concentration levels in the water overlying the sediments of all test levels. The WP concentrations in the water of the toxicity test, even at the end of 30 days, was 1000 times that found in the field over equally contaminated sediments. The toxicity test needs to be repeated with a different experimental design.

**Bouwkamp, C.A.** (1995) Evaluation of white phosphorus effects on the aquatic ecosystem, Eagle River Flats, Fort Richardson, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 335–402.

The purpose of these studies was 1) to determine if WP at ERF is having an adverse impact on the aquatic biota or bioaccumulating in the aquatic food chain and 2) to determine, through a laboratory invertebrate bioassay, a no-observable-effect level (NOEL) concentration for WP in sediment. Sediments and invertebrates from pond bottoms and gullies were collected at 23 sites in May and 39 sites in August. There is little evidence that the macroinvertebrate populations were affected at the highly contaminated sites based on the diversity, number of species, or number of organisms per unit area. No WP was detected in the invertebrates and stickleback fish living in the ponded areas of ERF except for low levels in three fish samples and one invertebrate sample in the fall 1994 study. The data from these studies indicate that a WP cleanup level would not be driven by effects on benthic macroinvertebrates or bioaccumulation in fish tissue.

**Clark, L., and J.L. Cummings** (1994) Field behavioral response and bead formulations for methyl anthranilate encapsulated bird repellents. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 281–294.

In the field we tested MA bead formulation JR930413A, 15% applied at 21.7 kg/ha, to evaluate its repellency to ducks. Overall, mallards tended to shift their site preference away from the area of the pens treated with MA beads as a function of experience. Similarly, there is a tendency for feeding activity to decrease at a faster rate within the bead-treated areas relative to the control. Subsequent formulations are being considered that show greater promise for stability in the field.

**Clark, L., and J.L. Cummings** (1995) Chemical hazing of free-ranging ducks in Eagle River Flats: Field evaluation of ReJex-iT™ WL-05. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 411–422.

Continued field testing of a chemical waterfowl repellent was carried out in ERF during 1994. Because water levels in the ERF were low and decreased during August 1994, waterfowl activity was concentrated into a few ponds. These conditions were ideal for the proposed chemical repellent treatment. Sufficient methyl anthranilate beads were applied to test areas in C Pond to provide adequate coverage of the sediment. The detailed behavioral data suggest that ducks readily recognized boundaries of treated areas and entered such areas only as a means of transit from one untreated site to another. There may be a minimum area effect for an effective treatment. A treatment of less than 0.1 ha did not appear to repel ducks from that area. As the cumulative total area of a treatment increased, the number of entries into the area decreased. These data are suggestive of an overall area repellent effect. We conclude that treatment of the sediment with encapsulated repellent may be a viable strategy to prevent ducks from using WP-contaminated areas. If used as a hazing tool on Eagle River Flats, methyl anthranilate beads should be employed over contaminated areas greater than 900 $m^2$ at an application rate of 0.017 kg of active ingredient per square meter.

The water column data on methyl anthranilate release show that loss of the repellent material is constant over time. However, in the field the data suggest a high level of integrity between 0 and 5 days, whereupon there is catastrophic failure of the bead, resulting in significant loss of methyl anthranilate. Given the organic nature of the shell (gel alginate), we suggest that the integrity of the bead is attacked by microbes as a nutrient source. The field failure rate for all beads tested to date is about 5 days and cannot generally be improved upon so long as a biodegradable gel alginate capsule is used.

**Clark, L., J.L. Cummings, C.H. Racine, B.B. Steele, and L.R. Reitsma** (1995) Integrated risk assessment model for determining white phosphorus encounter rate by waterfowl. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 403–410.

The objective of this study was to develop a simple method for risk assessment using WP encounter rate by dabbling ducks feeding in ERF. The general model, $M = cFW$, relates the probability of mortality $M$ to $F$, the proportion of time a duck spends feeding, and $W$, the probability of encountering a WP particle ($c$ is a proportionality constant relating $F$ and $W$). Data from telemetry studies, in which about 10% of the transmitter-collared ducks died ($M$), and feeding effort data for mallards indicated that 80% of their time is spent feeding. Using $c = 1$ and solving for $W$ $M$/$Fc$, the marsh-wide probability of encountering a lethal dose of WP is predicted to be 0.125. This value is in line with the percentage of all pond and marsh sediment samples having concentrations greater than 1 µg/g ( the level at which we can find actual WP particles). This model still requires refinement to account for differential use of specific habitats or site-specific feeding particularly since remediation would be site-specific. Therefore, another model is proposed that relates the probability of encountering a lethal WP particle to the particles per unit mass of sediment, the amount of time spent feeding, the duck's rate of feeding, and its efficiency in recovering particles of a certain size. Literature-based values for feeding rate and efficiency are available, but refinement of the particle size distribution per unit mass of sediment is still needed on a site-specific basis.

**Collins, C.M.** (1994) Pond draining treatability study. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 323–332.

Pond draining is an option under consideration for treating pond bottom sediments contaminated with WP. Pond draining would accomplish two distinct functions: 1) it would remove the pond as habitat for dabbling waterfowl, reducing the time the waterfowl spend feeding in a contaminated area, thus reducing the chances of WP poisoning; and 2) it would subaerially expose WP-contaminated pond bottom sediments.

A field test was conducted to determine the in-situ conditions of pond bottom sediments under drying conditions. The test results indicated that pond bottom sediments may dry sufficiently to permit WP concentration in the sediment to decrease. Surveys of potential pond draining locations were conducted. Based on the surveys of the gullies in the vicinity of the Bread Truck Pond, a drainage ditch connecting one or more gullies with the Bread Truck Pond could be constructed to drain the pond. The drainage ditch would be excavated to a depth of 1 m and would be between 50 and 150 m long, depending on location chosen. The drainage ditch would be excavated by explosives owing to the danger of UXO. Because of the extensive bulrush–wetland complex connected to the C pond along its east and northeast side, it does not lend itself to draining. A detailed survey of the eastern end of the Bread Truck Pond should be conducted next summer to confirm that the pond is hydrologically isolated from the C/D area. A preliminary pumping test should be conducted to confirm the feasibility of draining the pond prior to the construction of a permanent drainage ditch. A drainage ditch would then be designed and constructed that would lower the maximum water level within the pond, exposing much of the pond bottom sediments for an extended period during the summer. These sediments would then be monitored to determine soil moisture conditions and any decreases in WP concentrations.

**Collins, C.M.** (1995) Pond draining treatability study. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 529–562.

Work by M.E. Walsh has shown that WP contamination in intermittently flooded pond bottom sediments will also begin to sublime in situ if the sediments are subaerially exposed long enough for the sediment to dry below saturation. Whether the WP particles will disappear and how fast will depend on how long the sediments remain unsaturated and what the average soil temperature is. Isolated ponds that are contaminated with WP may not normally become dry enough to expose the contaminated pond bottom sediments or expose them long enough to become unsaturated. Therefore, artificially draining the pond, either temporarily or permanently, would expose much of the WP-contaminated bottom sediment, thus possibly allowing for the in situ sublimation of WP particles.

In this study the potential for draining a contaminated pond to a level where natural attenuation of WP could occur was investigated. The study was carried out in the Bread Truck (BT) Pond. Four sites were instrumented to monitor pond levels, sediment moisture, and temperature along a transect from a deeper, permanently flooded pond area, through the shallower, intermittently flooded area. A survey of the marsh area to the east of BT Pond showed that there was no direct connection between BT Pond and the C / D marsh–pond complex in the form of a channel or drainageway that would allow direct flow between the two areas. Site elevations ranged from 4.80 to 4.90 m.

A siphon system consisting of 165 m of 6.1-cm (4-in.) ID rigid PVC plastic pipe was installed from BT Pond to a tidal gully north of the pond. The siphon was filled and started on 25 June following the last flooding high tide. The pond level started dropping as water flowed out through the gully as well as through the siphon.

Even though large areas of pond bottom sediment were subaerially exposed, they did not dry sufficiently to allow dissipation of any WP contamination. Maximum soil temperatures at the 5-cm depths were 25°C for both sites, with an average temperature of 16°C. The siphon lowered the pond water level faster than natural draining and evaporation alone, but it was slow. However, it probably did not lower the pond level below that which it would have attained without the siphon. The soil moisture sensors at all depths at both sites did not change during the summer, indicating that the sediment remained saturated throughout the period.

**Collins, C.M., E.F. Chacho, M.R. Walsh, and M.E. Walsh** (1996) Pond draining treatability: 1995 studies. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 250–310.

The overall objective of this treatability study was to assess if pond draining is a viable option for remediating the WP-contaminated Bread Truck Pond in Eagle River Flats. To achieve that objective, several tasks were undertaken to determine if pond draining was technically feasible and what environmental conditions occur in the pond-bottom sediments following draining. Task 1 was to determine the environmental conditions in BT Pond before and after temporarily lowering the pond level by using a pump system. We installed instrumentation at eight sites along a transect through the intermittently and permanently flooded areas of the Bread Truck Pond to measure the sediment moisture and temperature monitored at 5- and 10-cm depths in the pond bottom sediment. We also continuously measured the water surface elevation of the pond. WP particles were planted in May at a depth of 5 cm at each site to monitor any reduction in size. Because of procurement delays for the pumping system, the pond was not drained and sediments remained saturated throughout the summer.

Task 2 was to design, procure, deliver, and install in the BT Pond a large dewatering pump system to be used to temporarily drain it. Design specifications of the integrated pump and generator system were determined in January 1995. We specified an integrated system consisting of a 2000-gal. / min electric-powered pump mounted on a float platform. A diesel-powered electrical generator to power the pump was mounted on a separate float platform. Integrated controls allowed automatic control of the generator and automatic startup and stopping of the pump system, controlled by float switches that would cycle the pump as the pond emptied or started to refill. Once funds became available, the requisition process was initiated in March 1995. Procurement problems delayed the award of the sole-source contract for the purchase of the system until July. During the first week of September the contractor completed the pump system and conducted a performance test at the contractor's facility in Montana. After the final tests, the pump system was shipped by truck to Anchorage, arriving on 12 September. Because the pump system was delivered so late in the season, it was not deployed to the Bread Truck Pond. Instead, we deployed the system in Clunie Inlet to completely test the system and to run the generator for the initial 40-hour break-in period. This allowed us to check fuel procedures and fuel consumption rates and to ensure that all sensors and controls were operational. Initially, we had some problems getting the controls to start the pump. It turned out that a control wire connection had come loose during transport and a fuse in the control panel blew after the loose wire shorted out. After we repaired the wire and replaced the fuse, the system was started normally. Water was pumped for approximately 7 hours a day for 5 days until the generator had the required 40 hours of running time on it. Following the completion of the test, the system was pulled out, the discharge line disassembled and the components shipped back to Ft. Richardson DPW for winter storage.

Task 3 was to determine the rate of surface water inflow into the C/D Area from the adjacent uplands and how that rate of inflow might influence the BT Pond. Two instrumented sites were installed in the C/D Area in early June to monitor water conditions. One site was located at the eastern edge of the C/D Area next to the upland border along the shore of a deep, narrow pond running parallel to the upland border. The second site was located at the far western end of the pond system that extends through the C/D Area toward the BT Pond, perpendicular to the first pond and the upland border. These two sites were instrumented to monitor pond water levels as well as water temperature, salinity, and specific conductance. Seven additional sampling sites were located along two transects, one parallel to the upland boundary and one perpendicular to the boundary. At these sampling sites, periodic water salinity and temperature measurement profiles of the water column were made and water quality samples taken. The measurements showed that a prism of fresh water discharged from a series of small springs and seeps along the upland border slowly displaced the brackish water that filled the ponds in this area after a flooding high tide. The formation and extension of the prism of fresh water as it rides over and displaces the brackish water could be seen in the weekly measurements of the water temperature and salinity of the water column at seven measurement sites. From the measurements, rates of inflow of fresh water were estimated. A model of freshwater flow was used to estimate a maximum volume of the freshwater inflow in the two connected ponds after 20 days of approximately 10,615 $m^3$. This equates to 530 $m^3$/day of fresh water produced by runoff, seeps, and springs along the 445-m total length of upland boundary bordering the pond system. This is equivalent to 0.0061 $m^3$/s, or only about 1/20 the pumping capacity of the pumping system to be installed in the BT Pond, indicating the system would be more than capable of keeping up with freshwater inflow from the C/D Area. Because of the unusually wet summer this year, with above-average rain from July through September, this discharge rate is probably higher than during an average summer.

**Collins, C.M., M.T. Meeks, and M.E. Walsh** (1998) Draining of Racine Island Pond by explosive demolition of a drainage ditch. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 63–80.

In April 1997 we successfully conducted an operation to permanently drain a pond in Eagle River Flats contaminated with white phosphorus. This pond, located in the center of Racine Island, was one the most highly contaminated in Eagle River Flats, with measured concentrations of white phosphorus of up to 3071 mg/g. We drained the pond by using explosives to excavate a drainage ditch connecting the pond with a nearby tidal drainage gully leading to Eagle River. This year's operation built on the success of a similar operation last year to drain Bread Truck Pond. Using explosives to excavate drainage ditches is an efficient and cost-effective method of permanently draining a pond where the potential dangers posed by unexploded ordnance (UXOs) preclude the use of conventional excavation equipment.

**Collins, C.M., M.T. Meeks, M.R. Walsh, M.E. Walsh, and R.N. Bailey** (1997) Pond draining treatability: 1996 studies—the draining of Bread Truck Pond. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 51–71.

On 30 April 1996, the Army conducted an operation to excavate a drainage ditch to drain a pond within Eagle River Flats using explosives. The pond was contaminated with white phosphorus from smoke munitions previously fired into the area. Because of a possibility of encountering unexploded ordnance (UXO) if the ditch was excavated using standard mechanical techniques, the ditch was excavated using military explosives. The operation was conducted by personnel of the 23rd Engineer Co., Ft. Richardson, as a training exercise, with the operation planned and coordinated by CRREL. The ditch was excavated in two stages. Seventeen 40-lb shaped charges were used to punch a series of 1-ft-diameter pilot holes straight down into the frozen ground and ice of the BT Pond and the adjacent land to a depth of 1.5–2.4 m. The total amount of explosives detonated in this first explosion was approximately 320 kg (700 lb). For the second stage, a 40-lb cratering charge was placed in each of the pilot holes created by the shaped charges. The cratering charges were linked together with detonation cord and then detonated. The total amount of explosives detonated in this second explosion was also approximately 320 kg (700 lb). The evenly spaced cratering charges produced a series of overlapping craters forming a ditch approximately 1.5 m deep, 3–4.5 m wide and 90 m long. Several short sections of blockages in the ditch prevented full flow through the ditch until a series of flooding high tides later in the spring eroded them out. Full flow through the ditch and drainage of the pond started on 22 May. By 21 June the BT Pond water level was 30 cm below the normal water level and occupied less than 10% of the original pond surface area. Prior to the next series of flooding tides starting 1 July, the exposed pond bottom had started to dry out and the surface cracked. Dataloggers continued to monitor water levels, soil temperature, and soil moisture conditions throughout the summer and fall.

**Cummings, J.L., L. Clark, and P.A. Pochop** (1994) Field evaluation: Mortality of mallards feeding in areas treated with methyl anthranilate. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 295–298.

We determined mortality of mallards feeding in pens treated with a modified MA formulation, JR930725. The mortality of ducks continuously exposed to WP-contaminated sediment was about 60% lower in treated pens within the first 24 hours after treatment. At the conclusion of the test (144 hours after treatment), the mortality was about 50% lower in treated pens. We anticipate that the relative risk of poisoning in MA-treated areas would decrease if the ducks were allowed to leave the area. Therefore, a study on free-ranging waterfowl is planned for 5–21 January 1994.

**Cummings, J.L., L. Clark, P.A. Pochop, and J.E. Davis** (1994) Laboratory evaluation of a methyl anthranilate bead formulation for reducing mallard mortality and feeding behavior. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 275–280.

We applied methyl anthranilate (MA) bead formulation JR930413 to bottom sediment in a simulated pond setting to evaluate its repellency to captive mallards. JR930413 was applied at a rate of 21.7 kg / ha or 7 beads / $cm^2$ to bottom sediment. It was effective in reducing the time mallards spent in pools. The average number of minutes mallards spent in pools decreased to below pretreatment levels. JR930413 applied to contaminated waterfowl feeding areas at 21.7 kg / ha could reduce feeding and mortality and warrants further testing in the field.

**Cummings, J.L., R.E. Johnson, K.S. Gruver, P.A. Pochop, and J.E. Davis** (1997) Movement, distribution, and relative risk of mallards and bald eagles using Eagle River Flats: 1996. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at*

*Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.*).* CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 21–30.

We determined spatial distribution, movements, turnover rate, and mortality of mallards using Eagle River Flats, Fort Richardson, Alaska, during fall migration, 3 August to 15 October 1996. Various techniques were used to capture 158 ducks on ERF. Of these, 107 mallards and 29 northern pintails were fitted with radio transmitters. Tracking data indicated that transmitters did not appear to inhibit movements or activities of either duck. Mallard movements and distribution indicate that they spent about 91% of their time in Areas A, B, C, and C / D. In addition, mallards spent about 83% of their time in areas that are considered contaminated (A, BT, C, C / D, EOD, and RI). The average number of days spent on ERF by mallards was 47. The average daily turnover rate for waterfowl was about 1.4%. The greatest turnover of waterfowl occurred from 1 to 15 October, when 62% of the mallards departed ERF. The mortality of instrumented mallards using ERF from 3 August to 15 October was 37, or about 35%. The greatest mortality occurred in Area C (35%), Area A (22%), and Areas C / D and RI (16%, respectively). During 1994 and 1995, 10 and 14 bald eagles were fitted with satellite transmitters. As of December 1996, only one transmitter remains active. That eagle was near Cordova, Alaska. No eagle mortality has been documented from instrumented birds, even though eagles scavenge dead ducks (including instrumented ducks). Indications from the 1996 data, compared to 1993 and 1995 mallard data, are that hazing is having a positive effect on the redistribution of waterfowl to uncontaminated areas on ERF.

**Cummings, J.L., R.E. Johnson, K.S. Gruver, P.A. Pochop, J.F. Foley, J.E. Davis, J.B. Bourassa, and C.H. Racine** (1998) Movement, distribution, and relative risk of mallards and bald eagles using Eagle River Flats: 1997. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.*).* CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 23–36.

We determined spatial distribution, movements, turnover rate, and mortality of mallards using Eagle River Flats, Fort Richardson, Alaska, during fall migration, 2 August to 22 October 1997. We randomly captured 136 mallards between 2 and 12 August on ERF using a net-gun from a Bell UH1 helicopter. Each mallard was banded and fitted with a 9.1-g backpack transmitter and released at its capture site. Of the 136 mallards, 55 were fitted with standard transmitters and 82 mallards were fitted with mortality transmitters. Tracking data indicated that transmitters did not appear to inhibit mallard movements or activities. LOCATE II was used to map telemetry locations. Mallard movements and distribution indicate that they spent about 88% of their time in Areas A, B, C, and C / D. In addition, mallards spent about 69% of their time in areas that are considered contaminated (A, BT, C, C / D, and RI). However, mallards were only located 6 of 144 times in Racine Island Pond and 2 of 21 times in Bread Truck Pond. The average number of days spent on ERF by mallards was 42. The average daily turnover rate for waterfowl was about 1.1%. The greatest turnover of waterfowl occurred from 7 to 16 October, when 52% of the mallards departed ERF. The mortality of instrumented mallards that used ERF from 2 August to 22 October was 35. Of that, 21 were attributed to white phosphorus ingestion. The greatest mortality occurred in Area BT, 5 of 21 (24%); Area A, 5 of 21 (24%); and Areas C / D and C, 7 of 21 (33%). Overall, these areas accounted for 81% of the mallard mortality on ERF. No mallard mortality was noted from capture, handling, or the transmitter. We recovered 15 whole duck bodies from the 21 white phosphorus mortalities. Analysis is planned. A mortality model was developed for ERF to estimate the total individual dabblers using ERF, the peak number of dabblers using ERF, and the total numbers of duck mortalities on ERF during the fall migration period. In 1996, 5413 individual dabblers used ERF from 3 August to 16 October. Dabblers peaked at 2333 individuals between 13 and 16 September. The overall mortality that occurred on ERF was 655 dabblers. In 1997, 6063 individual dabblers used ERF from 2 August to 22 October. Dabblers peaked at 4398 individuals between 9 and 10 September. The overall mortality that occurred on ERF was 240 dabblers. These data represent a minimum number of mortalities on ERF during the fall migration. In conclusion, we feel that the baseline data collected in 1996 and 1997 can be used to measure the effects of future remediation actions.

**Cummings, J.L., P.A. Pochop, and J.E. Davis** (1994) Waterfowl distribution and movements in Eagle River Flats. In *Interagency expanded site* *investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 227–234.

We determined the movement, distribution, turnover rate, and site-specific exposure of waterfowl species most susceptible to white phosphorus poisoning at Eagle River Flats during fall migration (August-September) 1993.

We captured 62 ducks of five species, mainly in Areas C, C/D, and Bread Truck with mist nets and swim-in traps. Of those, radio transmitters were attached to 12 mallards, 11 pintails and 11 green-winged teals. Tracking data indicate that during August (before hazing), telemetry species ranged over the entire Flats. Mallards tended to concentrate in Areas A and B, Racine Island and the C/D transition. Pintails used Area C and Bread Truck. Green-winged teal used the C/D transition area and shallow pools in Areas A and C. After hazing, most waterfowl concentrated in Area B and the C/D transition area. Preliminary data suggest that there was a low turnover rate of waterfowl species using the Flats during August and September. In addition, eight telemetry ducks were found dead on ERF: Racine Island (1), Area A (3), Area C (2), and the C/D transition area (2).

**Cummings, J.L., C.A. Yoder, R.E. Johnson, P.A. Pochop, K.S. Gruver, J.E. Davis, and K.L. Tope** (1996) Movement, distribution, and relative risk of waterfowl and bald eagles using Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 179–196.

This project determined the spatial distribution, movements, turnover rate, and mortality of waterfowl and bald eagles using Eagle River Flats during fall migration, 1 August to 17 October 1995. We captured 82 ducks and 14 bald eagles on ERF using various techniques. Of the waterfowl, 17 mallards, 16 northern pintails, and 21 green-winged teal were fitted with radio transmitters. Of the 14 eagles, 8 were fitted with satellite transmitters, the others with standard transmitters. Waterfowl transmitters were programmed to be on from August to November 1995, and again from April to June 1996. Eagle transmitters are expected to last 24 months. Tracking data indicated that transmitters did not appear to inhibit the movements or activities of either ducks or bald eagles. Daily waterfowl movements indicate that all species moved among areas quite readily. Mallards spent about 60% of their time in Areas B and A; pintails spent about 87% of their time in Areas A, C/D, and D; and teal spent about 63% of their time in Areas A and D. After the hazing program was started, waterfowl use patterns changed on ERF. The average number of days spent on ERF by mallards, pintails, and teal was 40, 46, and 27 days, respectively. The average daily turnover rate for waterfowl was about 3.8%. The greatest turnover of waterfowl occurred prior to 5 September, when 47% of mallards, 37% of pintails and 43% of teal departed ERF. The mortality of instrumented ducks using ERF from 1 August to 17 October was five ducks, or about 9%. Most of the telemetry contacts with eagles, excluding the two nesting birds, indicated that eagles spent an average of 1.4 days on the Flats. Instrumented eagles were only observed in Areas A, C, and C/D during the spring and A and C/D during the fall. The nesting success of eagles on ERF did not differ significantly from eagles nesting on Susitna or Chickaloon Flats. Eagles on ERF produced an average of 1.3 eggs and fledged an average of 0.33 eaglets. No adult eagle mortality has been documented from instrumented birds, even though eagles scavenge dead ducks (which has included instrumented ducks).

**Cummings, J.L., C.A. Yoder, R.E. Johnson, P.A. Pochop, K.S. Gruver, J.E. Davis, K.L. Tope, J.B. Bourassa, and R.L. Phillips** (1995) Movement, distribution, and relative risk of waterfowl, bald eagles, and dowitchers using Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 321–334.

We determined spatial distribution, movements, turnover rate, and mortality of waterfowl, bald eagles, and dowitchers using Eagle River Flats, Fort Richardson, Alaska, during spring migration, April–May 1994. We captured 34 ducks, 20 dowitchers, and 10 bald eagles on ERF using various techniques. All birds were fitted with radio transmitters. This included 27 mallards, 4 green-winged teal and 1 northern pintail. Of the 10 eagles, 3 were fitted with satellite transmitters. All eagle transmitters are expected to last 17 (standard) to 24 months (satellite). Tracking data indicated that mallards and teal averaged 6.8 days (range 1–17 days) on the Flats. Average daily turnover for waterfowl was about 5%. Waterfowl mortality during the spring migration period was about 12%. Mallards and green-winged teal tended to concentrate in areas C, C / D, and D. Waterfowl spent more time in areas B and D, and off the Flats after hazing. Bald eagles spent an average of 2.9 days on the Flats. Most of the telemetry contacts with eagles were in the wooded area bordering ERF. Eagles fitted with satellite transmitters are currently near Kodiak Island and Cordova, Alaska. No eagle mortality was documented; however, a mallard transmitter was found in an eagle nest on ERF. Dowitchers spent an average of 6.8 days on the Flats and mainly foraged in highly contaminated areas without any mortality.

It is recommended that telemetry data be integrated into the Integrated Risk Assessment Model; that future remediation actions be assessed with telemetry studies; that research efforts on shorebirds be minimized; and that monitoring of those bald eagles breeding on ERF be continued.

**Eldridge, W.D.** (1994) Waterbird utilization of Eagle River Flats: April–October 1993. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 191–204.

The Anchorage area experienced a mild April and May 1993, and considerable habitat was open to waterbirds when they began arriving in mid-April. As a result, birds did not concentrate on ERF, and numbers were less than in 1992. Additionally, improved hazing techniques discouraged waterbird use in 1993. Alaska experienced a mild fall in 1993, with the result that migration through Cook Inlet occurred without big influxes of birds caused by early or dramatic freezing elsewhere in the state. After a short cold spell in middle to late October, temperatures moderated, allowing ducks to remain in upper Cook Inlet until mid-November, almost 3 weeks later than normal.

**Eldridge, W.D.** (1995) Waterbird utilization of Eagle River Flats: April–October 1994. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 277–288.

The objective of the 1994 aerial waterbird survey was similar to that of previous aerial surveys of ERF, initiated in 1988: to monitor waterbird abundance and distribution on ERF during spring, summer, and fall. A total of 43 aerial surveys was conducted from April through October 1994. Flights were made generally twice per week during spring and fall and once per week during summer.

**Eldridge, W.D.** (1997) Waterbird utilization of Eagle River Flats and Upper Cook Inlet: April–October 1996. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 7–18.

We conducted 34 aerial surveys of Eagle River Flats (ERF) during spring, summer, and fall of 1996 as part of ongoing waterfowl mortality studies sponsored by the U.S. Army. Generally spring was late in 1996, so ERF received less use by ducks and swans than in previous years. Use by geese was similar to other years. The summer was very dry in 1996, but some permanent ponds retained water and several broods of ducks and geese were observed. Fall tides flooded most of ERE in late August. The fall was generally mild, which allowed waterfowl to move through the region at a leisurely pace and there were no large buildups in waterfowl populations. Numbers of swans on ERF in fall were lower in 1996 than in previous years. Numbers of ducks and geese were higher than in previous years, possibly because of the decreased human activity and hazing in 1996. Swans used Areas A and B the most during fall. Geese used Coastal East and West the most, and ducks were more evenly distributed in fall, utilizing Coastal West and Area B slightly more than the other areas.

**Eldridge, W.D., and D.G. Robertson** (1996) Waterbird utilization of Eagle River Flats and Upper Cook Inlet: April–October 1995. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 131–156.

We flew 37 surveys aerial surveys over Eagle River Flats from April to November 1995 with a single-engine, fixed-wing aircraft using standard USDI methodology. 1995 was a wet year in upper Cook Inlet, so ponds were full most of the season. Fall weather was mild, which delayed migration through upper Cook Inlet. Numbers and species of waterbirds counted on ERF were similar to other years, dominated by dabbling ducks and Canada geese, particularly in fall. Utilization of standard study areas within ERF by waterbirds was recorded and presented by season.

Other marshes in upper Cook Inlet were surveyed in 1995 to compare to ERF. These included Palmer Hay Flats, Goose Bay, Susitna Flats, Trading and Redoubt Bays, and Chickaloon Flats. We conducted 25 surveys from April to May. More than 90% of the waterbirds counted were found on marshes other than ERF during the season. Waterbirds concentrated on broad intertidal mud flats in marshes other than ERF, Goose Bay, and Palmer Hay Flats, where this habitat type is poorly represented. Species composition of waterbirds was similar on all areas. Numbers by species and area are presented by season.

**Eldridge, W.D., and D.G. Robertson** (1998) Waterbird utilization of Eagle River Flats and Upper Cook Inlet: April–October 1997. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 7–22.

Waterbird utilization of Eagle River Flats (ERF) was monitored during spring, summer, and fall 1997, with 36 aerial observations. Numbers of waterbirds, identified to species or species group, were recorded by study area and pond number within the study area, and by four major habitat types. ERF became snow and ice free earlier than in 1996, experienced extremely dry conditions during summer, and experienced normal water levels in fall, with a relatively early freezeup. Numbers of swans in spring and fall were similar to 1996 but considerably lower than the 1988–95 average. Numbers of geese were similar to recent years. Duck utilization of ERF was minimal in spring 1997, but normal for summer, despite the low water levels. Duck migration in fall 1997 exhibited a strong peak in early September rather than the protracted series of peaks normally observed, but the mean number for fall was similar to the 1988–95 average. Ducks preferred areas Areas B, C, and CD most in fall, with highest densities in Areas B and CD.

A comparison of air and ground counts on the same survey dates in fall was made to develop a correction factor for birds missed from the air, and to obtain a more accurate species composition of ducks. There were no statistical differences between counts of geese and swans from the air and ground, but there was a statistical difference between duck counts. Biases associated with the air–ground comparison probably make the counts unreliable for air–ground corrections. The ground counts do provide reliable counts for species composition.

**Haugen, R.K.** (1995) Climate and tides. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 187–200.

Meteorological elements and tidal inundations are the major driving forces for physical and biological processes within ERF. In May 1994 a meteorological site was installed at ERF next to the EOD pad to provide baseline data for ongoing investigations. Comparisons between ERF and the Anchorage climatic record (Anchorage airport) showed that daily maximum temperatures were about 1°C lower at ERF and minimum temperatures 2.3°C lower. A comparison of mean daily air temperatures between the ERF main site at the EOD pad and an ERF coastal meteorological site had a 5.3°C difference, showing that air temperature variances within ERF are greater than the ERF / Anchorage differences.

A historical analysis of Anchorage temperature and precipitation from 1917 to the present was done to compare the normalcy of the weather during the ERF project on a monthly basis. The ERF field seasons of 1993 and 1994 can be characterized as normal except that May 1993 was more than one standard deviation warmer and wetter than normal, and August 1994 more than one standard deviation warmer and drier than normal.

A program for the development of tidal tables was obtained from NOAA and adapted to predict past and future periods of tidal inundation of ERF. A table of predicted tides high enough to flood ERF for the months of May through October is given for the period 1994–1997. Additional tables for 1960–2000 were produced for comparisons with the historical climatic record, previously mentioned, of tidal inundation, air temperature, and precipitation for the ERF area to determine the frequency of extended periods of pond draw-downs and drying soil moisture conditions. Such data are of considerable importance to the fate of white phosphorus in the soil.

**Haugen, R.K.** (1996) Climate and tides. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 113–130.

Weather and tidal activity provide the driving forces for physical and biological processes in the Eagle River Flats area. A meteorological site was installed at the edge of the EOD pad in May 1994. This station has provided a basis for climatic comparisons with Anchorage and other study locations at ERF. Data obtained at the EOD meteorological site included air, ground, and surface temperatures, incident and reflected solar radiation, relative humidity, wind speed and direction, and precipitation. A comparison with the 1994 season (May–September) shows that the seasonal average temperature during 1995 was about the same but that precipitation during the 1995 season (250 mm) was over twice that of the 1994 season.

A comparison of 1995 air temperature data for 30 May to 29 October between the EOD site, ERF coastal site, and Anchorage showed Anchorage temperature to be higher than EOD by 2.3°C, and EOD to be higher than the ERF coastal site by the same amount. The 1994 ERF report showed the coastal site to be warmer than the EOD site, but it is now apparent that daily maximum temperatures were used to represent the coastal site in the 1994 analysis, rather than the daily average temperatures. The –2.3°C difference found with the 1995 data between the EOD pad site and the coastal site should be considered representative.

Data analysis includes discussion of relative humidity, wind speed, and air and ground temperature at the EOD site, together with solar radiation. Comparisons between net solar radiation, soil surface temperature, and soil moisture measurements are shown graphically. Evapotranspiration rates for the ERF area and for historical time series were calculated. An existing computer program was used to calculate evapotranspiration with different methods, depending on the amount of available input data. Anchorage *Summary of the Day* records were obtained back to 1952 to calculate historical means and extremes for the summer season for a large number of parameters. Time series of tidal flooding gaps using three flooding heights, precipitation, and estimated evapotranspiration were developed for the growing seasons of 1995–2000. These data should be useful for planning research and remediation activities.

**Henry, K.S.** (1994) Geosynthetic covering of contaminated sediment. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 299–304.

Conclusions from pilot field testing in ERF of four geosynthetic products, tested to limit exposure of dabbling ducks to WP, in 1992 and 1993 include: 1) the bubble formation in products A, B, and C placed in ERF is attributable primarily to the formation of gas in the pond sediments; 2) the anchoring methods used on the test site were inadequate for the environment of Area D; and 3) no bubbles formed in product D installed in the ERF (this was the 2.5-cm netting underlain by coconut fibers). Future work on geosynthetics should address the problem of providing a barrier that: 1) limits exposure of wildlife to WP and 2) allows gas formed in the ERF to escape. A variety of products could be tested, including a geotextile–geomesh composite. The geotextile would be the bottom layer of the composite, serving as a separator, and would have large-diameter holes cut in it at a regular spacing (e.g., 0.3-m diameter, spaced 1 m apart on center). Other barriers might include a large-pored biodegradable product for use as a temporary barrier. The survivability of products should be determined; this includes resistance of the fabric to damage that would hinder its intended function and determining suitable means of anchoring the products so that they remain in place in the various environments in which they would be placed. The interaction of any barrier remediation technique with the environment needs to be determined, e.g., changes in sedimentation, water levels, vegetation, and wildlife behavior because of its presence. Adverse and beneficial impacts on the environment should be determined.

**Henry, K.S.** (1995) Screening study of barriers to prevent poisoning of waterfowl in Eagle River Flats, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 445–470.

The objective of the study was to evaluate the potential of four geosynthetic barriers to prevent the movement of WP from beneath the barrier to above it. Emphasis was on the retention of particles larger than 0.15 or 0.25 mm in diameter. A field test in Area C Pond involved the establishment of five test circles (A, B, C, D, and a control without any geosynthetic), 2.4 m in diameter, constructed with a clear plastic Lexan barricade (to prevent mixing of water on the inside and outside of the barrier). The bottoms of three circular plots were covered by a geocomposite (consisting of a needle-punched polyester geotextile approximately 540 $g/m^2$, with an apparent opening size of 0.149 mm) overlain by a drainage matrix material (geomesh) consisting of an nylon entangled mesh. The geotextile had 8-cm-diameter holes cut into it, 0.3 m on center, to allow for the venting of gas. In one of these three test cells, an 8-cm-thick bentonite layer, provided by the Denver Wildlife Research Center, was placed on top of the geocomposite. A 10-cm gravel fill layer, provided by Ft. Richardson, was placed on top of the geosynthetic in a second circle. No gravel or bentonite layer was placed over the third test cell geocomposite. A biodegradable woven coir (a fiber made from coconut husks) mat was used to cover the ground surface of the fourth test cell.

We disturbed the barriers by vigorously stirring the water with a canoe paddle and by dropping a mass onto it to simulate a moose walk. The responses measured were amounts of sediment resuspended during the test and percentage of the resuspended sediment particles that were larger than 0.15 mm and that were larger than 0.25 mm. The results showed that the barriers reduced the amount of sediment resuspended by about 30% or more. The sediment that moved across the barriers contained less than 3% by weight of particles larger than 0.15 mm in diameter. The barrier consisting of geocomposite covered with 10 cm of gravel was most effective. None of the barriers tested were damaged by loading tests that simulated a moose walking.

**Lawson, D.E., S.R. Bigl, and J.H. Bodette** (1994) Physical system dynamics. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 25–84.

Eagle River Flats is an estuarine salt marsh that is actively undergoing progressive and significant changes in the physical environment. These changes result from the interaction and response of multiple physical processes to various factors, including external forces such as a high tidal range, a glacial river, two relatively large sediment sources, and a cold climate. The location of ERF within an active earthquake zone adds further to the complexity and the potential for future rapid, probably unpredictable, physical changes. In addition, ground explosions and cratering during the use of ERF as a military firing range since the early 1940s have caused physical changes to the terrain, hydrology, and surface drainage. The inherent complexity of this dynamic environment makes it extremely difficult to predict if and how WP particles in the sediments might be transported and what effects potential remedial measures will have on the physical system and conversely what short- and long-term effects the physical system will have on proposed remedial measures. Understanding both the system's response and the effects of such remedial measures are critical to deciding on cleanup actions.

Sedimentation rates in ponds and mudflats are relatively high, ranging from l0 to 15 mm on mudflats and 20 to 40 mm in ponds. The primary source of this sediment is tidal inundation, which carries sediments from Knik Arm (Cook Inlet) or Eagle River or both. The timing and height of maximum tidal flooding of ERF (based on measurements in the Bread Truck and C Pond areas) is controlled mainly by tides but enhanced by the discharge of the Eagle River (whose discharge is controlled in turn by glacial melt and precipitation). Preliminary analyses suggests that sedimentation in the coastal two-thirds of ERF is tidally dominated, whereas the inland one-third is apparently river-dominated.

While sedimentation rates are high, erosion and recession of the headwalls and lateral walls of gullies are also relatively high. Gullies are therefore progressively extending into the mudflats toward the Bread-Truck–C-Pond complex. Headwalls and adjacent lateral walls receded at rates ranging from 0.1 to 4.9 m during the summer of 1992, 0.4 to 6.3 m during the winter of

1992–93, and 0.0 to 9.8 m during the summer of 1993. Two gully headwalls are advancing at a rate sufficient to cause increased drainage of ponds within the next 10–15 years if the 1993 rates are characteristic.

**Lawson, D.E., S.R. Bigl, L.E. Hunter, B.M. Nadeau, P.B. Weyrick, and J.H. Bodette** (1995) Physical system dynamics, WP fate and transport, remediation and restoration, Eagle River Flats, Ft. Richardson, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 53–186.

This study analyzes the physical processes of erosion, sedimentation, and sediment transport, the factors controlling their activity, and the physical transport of WP within ERF. Potential physical system responses to natural or anthropogenic remedial measures, and the potential effects of the physical system on proposed remedial measures, are also discussed. Our investigations of the physical system over the past 3 years have significantly improved knowledge of the processes actively changing ERF and determining the flux of sediment and water within the system.

Tidal height fluctuations were measured in 1994 in concert with water level changes in eight major tidal gullies and in the Eagle River where it discharges into ERF. These measurements define the timing and distribution of flood and ebb waters and qualitatively assess the contribution of the Eagle River discharge to flooding. Suspended sediment concentrations were also measured in the Eagle River, gullies draining the ponds and mudflats, and Knik Arm to define the contribution of these sediment sources to pond and mudflat sedimentation. Salinity, temperature, dissolved oxygen (DO), pH, and turbidity were measured to assess the contributions of tidal or riverine water masses to flood and ebb cycle white phosphorus (WP) sedimentation, transport, and erosion. Hydrologic parameters, including drainage pattern, channel gradients, channel cross sections, and flow velocity, were also analyzed to calculate ebb discharge and sediment and WP particle transport rates, and to model sediment and water flux. Over 200 sediment samples were collected and analyzed for WP.

The results of our studies have shown that the ERF system is extremely complex, with multiple internal parameters that vary daily, seasonally, and annually and with long-term external controls. The natural system is governed by a high tidal range, glacial river influences, large sediment influx from two distinct sources, and a subarctic coastal climate. In addition ERF is located within an active earthquake zone that increases the potential for rapid and unpredictable physical changes in the future. The use of ERF as an artillery impact range has also produced explosion craters, which have caused physical changes to the terrain, hydrology, and surface drainage.

*Tides*

The elevation and duration of tidal inundation affect sedimentation. Tidal flooding of the Bread Truck, C Pond, A, and Racine Island Areas is enhanced by the discharge of the glacially fed Eagle River, with its timing, peak height, and duration affected by seasonal peaks in meltwater discharge and precipitation in the river's watershed. In contrast, tidal inundation is related to tide height in gullies closer to the coast. Similarly, the direction and velocity of the wind across ERF preceding and during tidal inundation may either enhance or reduce the height and duration of inundation. Storm-driven water masses in Cook Inlet may have the same effect on flood height in Knik Arm. Limited data indicate ice and snow cover can enhance the height and duration of flooding as well.

A comparison of water level variations at the heads of eight gullies across ERF and in the Eagle River showed a 20- to 40-mm delay in the timing of the peak tidal flood height relative to that predicted at Anchorage by tide charts. When the predicted tide height is sufficiently high to flood part or all of ERF, the actual peak elevation exceeds that height. Flood height is generally greater than the Anchorage datum by 0.5 m or more, with the amount dependent on the volume of glacial meltwater in the Eagle River and possibly Knik Arm. The general increase may be caused by the constriction in Knik Arm south of ERF.

*Suspended solids*

The total suspended solids (TSS), or suspended sediment concentrations, in waters of ERF vary with tidal stage, location, source, and season. The glacially fed Eagle River varies seasonally from peak TSS values of 100–700 mg/L between breakup in May and freezeup in October. Two seasonal highs occurred in 1994, the first in early June during snowmelt runoff and the second in early August during the peak glacial melt season. In contrast, waters of Knik Arm ranged from about 1000 to 2800 mg/L from May to October and appear to be the primary source of new sediment in ERF. A range in TSS values similar to that of Knik Arm characterized the eight gully sites, indicating this causal relationship. During any given tidal cycle, TSS values steadily increased with the flooding tide, but progressively decreased at a slower rate during the ebb. Seasonally, TSS values in gully and Knik Arm waters increased from spring to fall; the cause of this increase is unknown and under study.

*Sedimentation*

Sedimentation ranges from several millimeters per year on levees, 10–15 mm on mudflats, and up to 20–40 mm per year in ponds. If the high sedimentation rates measured in ponds are characteristic, natural sedimentation would aid in infilling of dredged areas and may provide a method of burying and thereby naturally avoiding WP ingestion by waterfowl.

Eagle River provides access for tidal waters to inundate the innermost reaches of the Flats. Increases in water level and reduced or halted flow result from tidal damming by incoming floodwaters that may lead to localized increases in depositional rates. Preliminary analyses indicate that sedimentation in the northern two-thirds of ERF is tidally dominated, whereas the southern one-third appears to be river-dominated. Sediments deposited by the Eagle River at the head of the Flats where it enters ERF proper has apparently formed an alluvial fan with four radially spreading channels of Eagle River distributing water after entering the tidal flats.

At the exit of Eagle River into Knik Ann, 6 hours of bathymetric profiling of Knik Arm offshore of ERF revealed the existence of two submarine channels. The primary channel is 100–200 m wide and generally parallels the coast. The secondary channel is located about 1–1.2 km offshore and characterized by erosional features. Large intertidal bars occur north of the Eagle River mouth, and west of the primary channel. These bars, as well as a zone adjacent to the coastline south of the Eagle River mouth, are potential depositional repositories for WP.

*Erosion*

Erosion and recession rates of headwalls and lateral walls of tidal gullies are also relatively high. Rates ranged from 0.1 to 4.9 m during summer 1992, 0.4 to 6.3 m during winter 1992–93, 0.0 to 9.8 m during summer 1993, 0.0 to 2.3 m in winter 1993–94, and 0.0 to 2.6 m in summer 1994. Gullies are progressively extending into the mudflats toward the pond complexes of the Bread Truck, C, A, D, and C/D. Two gully headwalls, one on the western side of Bread Truck and the other near the pond complex between Bread Truck and C ponds, are advancing at a rate sufficient to cause increased drainage of those ponds within the next 15–30 years if the average rates persist. Surveyed longitudinal profiles of tidal gully thalwegs revealed unstable, nonequilibrium gradients that reflect their progressive elongation into the mudflats and ponds by headwall erosion. Headwalls have nearly vertical faces that vary from 1 to 2.5 m in height. Above them, gradients within drainageways range from 0.001 to 0.004 m/m across the mudflats and into the ponds, being slightly lower in slope than within the tidal gullies below the headwall. Tidal current velocity data from three gullies indicate that sediment transport and channel erosion are potentially greatest during the ebb cycle.

*White phosphorus transport*

There is some area-specific evidence for the movement of white phosphorus via ice-rafted sediments, resuspension in ponds (measured in sediment traps), and ebb tide gully discharge water (captured in plankton nets). Concentrations found to date are too low to indicate actual particle movement, but WP is moving locally in some form. In the case of ice-rafted WP, contaminated pond bottom sediments can freeze onto the ice bottom during its growth and subsequently be uplifted and transported during tidal inundation. Ice and water erosion and transport of WP remain to be quantitatively assessed.

*Remediation*

Natural attenuation of WP contamination as the result of sedimentation and burial, erosion and pond drainage, abrasion during transport, and other causes needs to be considered. The inherent complexity of this dynamic environment makes it extremely difficult to predict what effects potential remedial measures for white phosphorus (WP) contamination will have on the physical system. Because the physical conditions and processes vary widely across ERF, each specific area slated for WP remediation needs to be evaluated and ranked in terms of the suite of potential remedial measures and their probable effectiveness and success over the short (1–5 years) and long (10–50 years) term. It is equally important that the impact of these treatment methods on the physical system be evaluated before a remedial technology is selected. For example, in some areas dredging may create conditions that will enhance sedimentation and significantly reduce the need for site restoration. In other areas of ERF, dredging may modify the hydrology such that gully erosion increases, thereby altering the drainage system and perhaps extending it into the dredged area. Dredge operations may disturb underlying sediments, thereby increasing their susceptibility to erosion.

Site-specific effects of erosional processes must be considered before remediation is initiated. Erosion, for example, can affect the integrity of measures such as capping by AquaBlok™ or geotextiles. Both ice and currents are critical mechanisms in this regard. Ponds in which WP contamination is remediated by temporary drainage and drying may subsequently have clean sediments uplifted and removed by ice, thereby exposing WP-bearing sediments below. Similarly, areas remediated by removal of WP-bearing sediments may be infilled with WP-bearing sediments that were eroded elsewhere in ERF and then transported and redeposited at the site.

*Information needs*

A conceptual model of the physical ecosystem and WP fate and transport remains to be developed. Some specific gaps in knowledge of the physical system include very limited data on WP transport and persistence, groundwater hydrology of ponds and marshes, environmental controls on WP deposition in the Eagle River and Knik Arm, and the factors, controls, and interactions of processes causing long-term morphologic changes that will affect WP remediation.

**Lawson, D.E., L.E. Hunter, and S.R. Bigl** (1996) Physical system dynamics, WP fate and transport, and remediation. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 21–112.

The focus of these investigations was on the role of the physical system in the burial or transport of white phosphorus in this tidal flat area. Specifically, these investigations evaluated whether the processes of gully erosion, headward recession, and drainage of contaminated ponds, and of burial of contaminated pond sediments, could produce a natural attenuation of WP contamination. The erosion and potential for off-site transport of WP was examined.

Several important conclusions result from this and previous year's work:

- Physical system processes result in the burial and transport of WP.
- Gully erosion and headwall recession will drain areas of contaminated ponds in about 1–10 years, potentially resulting in in-situ WP degradation and attenuation via drying. This is a cost-effective alternative to artificial pond draining. Historical analyses, field data, and process analyses indicate that Bread Truck Pond will probably begin draining in 1 year, while C / D, Lawson's Pond, and a large area of C Pond will begin to drain in 10–15 years or less.
- Pond sedimentation rates are high and could, over time, bury WP-contaminated pond sediments to a depth sufficient to prevent feeding waterfowl exposure.
- Natural sedimentation and burial, perhaps artificially enhanced in some locations by introducing additives to increase flocculation, is a cost-effective alternative to the installation of a barrier, particularly in certain pond areas. Gully erosion and extension may subsequently drain and dry these same areas, furthering the permanency of remediation.
- Ice rafting can move WP by plucking it from the bottoms of contaminated ponds and moving it to other areas.
- WP in sediments is eroded from ponds and drainages by ice and water and subsequently transported by currents into the Eagle River and possibly off-site (Knik Arm), where its fate is unknown. Contaminated sediment is also transported to other locations within ERF.
- Racine Island Pond has neither high gully erosion and headward recession rates, nor high sedimentation rates. This pond also floods at relatively low tidal heights and contains organic-rich sediments. It appears, therefore, that it can only be effectively remediated and readily restored through artificial drainage and temporary berm containment to permit long-term drying and in-situ WP degradation.

Based on the investigations to date, the following recommendations are made:

- Cost-effective remediation can be accomplished to a significant degree by allowing the physical system to remove or isolate WP contamination over time.
- WP contamination of Bread Truck Pond and 50% or more of C Pond, including potentially Lawson's Pond in the long term, should be treated by natural or enhanced drainage and subsequent in-situ WP degradation by drying.
- Sedimentation and burial of WP may be effective in removing it from feeding waterfowl in the short term; in the long term, burial will reduce waterfowl mortality during natural pond drainage in the C, Lawson's and C / D Pond areas.
- Racine Island Pond may be effectively remediated by gully extension, artificial pond drainage, and pumping, and long-term containment with a temporary berm to permit in-situ WP degradation by extended drying of pond bottom sediments. By simply removing the berm after WP has attenuated naturally, the pond environment will be restored.
- Erosion and recession rates, pond sedimentation, groundwater, pond drainage, and drying, and WP degradation and attenuation should be monitored to ensure that remediation is taking place as predicted by physical system analyses and to assess ecosystem impacts of artificial remediation techniques during feasibility studies and remediation.
- WP migration and contamination in Knik Arm should be evaluated, focusing on areas of near-shore zones and mid-Arm bars where there is a potential for WP exposure to receptors.
- The potential for natural attenuation of white phosphorus as the result of mechanical abrasion during transport by gully and tidal currents should be evaluated.

**O'Neil, P.** (1994) Hazing waterfowl in ERF. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 267–273.

During parts of May, September, and October of 1993 under Agreement 12-34-73-2158, USDA / APHIS / Animal Damage Control (ADC) continued efforts to keep migratory waterfowl from being poisoned by white phosphorus in the U.S. Army's Eagle River Flats (ERF) Impact Area at Ft. Richardson, near Anchorage, Alaska. The work involved the use of a variety of traditional hazing methods over discrete, limited areas within Eagle River Flats, with other less-contaminated areas remaining as undisturbed sanctuaries.

**Pochop, P.A., J.L. Cummings, L. Clark, and J.E. Davis** (1994) Evaluation of Concover® and BentoBalls™ on contaminated sediments to reduce mortality of foraging waterfowl. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 305–312.

We evaluated the feasibility of applying two materials, Concover® and BentoBalls™ barrier system, on contaminated sediments to provide a physical barrier to foraging waterfowl. Laboratory trials were performed to determine if either product would stand up to field trials. Visual inspections during laboratory trials indicated that the Concover® was immediately penetrated by the water and readily torn up by mallard activity. In contrast, daily inspections of the BentoBalls™ indicated that it appeared to maintain its structure under mallard use. Therefore, the BentoBalls™ barrier system was used in the subsequent field trial.

The field trial was conducted from 14 to 30 June 1993 at Eagle River Flats. During the pre-treatment all of the ducks died in the control and half of the ducks died in the BentoBalls™ pen within the first 6 days. However, no ducks died in the BentoBalIs™ pen during the last 2 days of the pre-treatment. During the post-treatment all of the control ducks and none of the BentoBalls™ ducks died. Observations of the BentoBalls™ 42 days after application indicated that algae was growing on it. During a follow-up trial on 6–13 August 1993, more control than treated ducks died up to 55 hours of exposure. However, there were no differences in mortality after 70 hours.

The results of laboratory and field trials of Concover® and BentoBalIs™ indicates that the BentoBalls™ barrier system has potential for reducing waterfowl mortality and warrants further studies to determine its effectiveness and longevity for a potential method of remediation on Eagle River Flats.

**Pochop, P.A., J.L. Cummings, and C.A. Yoder** (1995) Evaluation of AquaBlok™ on contaminated sediment to reduce mortality of foraging waterfowl. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 429–444.

The results of a 1993 pilot study indicated that the AquaBlok™ barrier system could reduce mortality of foraging waterfowl on Eagle River Flats, Alaska. Therefore, a definitive study was conducted in 1994. Our objectives were to evaluate the longevity of AquaBlok™ when applied to an isolated pond up to 0.5 ha in size and to measure its effects on waterfowl foraging behavior and mortality on Eagle River Flats. During pretreatment, 23 mallards *(Anas platyrhynchos)* died in the control pen and 15 died in the treated pen over 10 days; during post-treatment, 24 mallards died in the control pen and 3 mallards died in the treated pen. During pre-treatment, the mallards in the treated pen were observed feeding more than those in the control pen. However, control ducks were observed feeding more frequently post-treatment. Data collected to date indicates that AquaBlok™ shows promise for reducing waterfowl mortality from white phosphorus poisoning on Eagle River Flats, Alaska.

**Pochop, P.A., J.L. Cummings, and C.A. Yoder** (1996) Evaluation of AquaBlok™ on contaminated sediment to reduce mortality of foraging waterfowl. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 205–230.

The results of a study conducted in 1994 by covering the bottom of a pond indicated that AquaBlok™, a physical barrier to foraging waterfowl, could reduce mortality of waterfowl when applied to a WP-contaminated pond up to 0.5 ha in size. The objective in 1995 was to continue to evaluate the effectiveness of this barrier. Emergent vegetation growing through or on the AquaBlok™ recovered from 45% in 1994 to 76% in 1995. In 1991 (before application), vegetation cover in the pond was only 52%, indicating that there was no adverse impact of the AquaBlok™ on the vegetation. Analysis of AquaBlok™ indicated that WP concentration varied from below the detection limit to 0.02 mg/kg (mean = 0.01 mg/kg) of WP and was probably contamination from the sediment below the barrier. No mortality of waterfowl was observed during a second year of AquaBlok™ exposure to weather and tide events. AquaBlok™ thickness was reduced by 0–5 cm from values in 1994. However, this was largely influenced by heavy traffic (animal and human) and limitations in the sampling method. Tide plots indicated that erosion and movement of AquaBlok™ were lowest on Racine Island, where vegetation was important in stabilizing the barrier.

**Racine, C.H.** (1994) Habitat and vegetation. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 5–23.

Five zones and 18 habitat-vegetation types occur on the 865-ha Eagle River Flats, an estuarine salt marsh on upper Cook Inlet. These zones are arranged both longitudinally from the coastal inlet inland and laterally from the river toward the upland. The *mudflat/distributary zone,* located nearest the river and coastal inlet, occupies 30% of ERF and is influenced by actively eroding distributary channels cutting across the mudflats. Vegetation cover varies from bare sediment areas to sparse cover by annual plants and alkali grass to well-vegetated stands of arrowgrass, beach rye, and goose tongue. Geese graze in this habitat during early spring, and sandhill cranes use the area throughout the summer. Just inside the mudflat/distributary zone is a continuous or fragmented *sedge meadow zone* dominated by Ramenski's sedge and covering about 8% of ERF. A *pond/marsh zone* (17% of ERF) is located inside this sedge meadow zone and includes bulrush and Lyngbyaei's sedge ponds up to 50 cm deep with well-developed submerged aquatic vegetation. This area is important feeding habitat for dabbling ducks and swans. A *sedge marsh zone* occupies the inland end of ERF (30% of the Flats) where the glacial Eagle River enters and accounts for any flooding and sediment deposition. Finally, a *border zone* (5% of ERF) with various forest, shrub, and sedge bog communities occurs in two embayments along the upland edge. The channel of Eagle River occupies about 8% of ERF.

**Racine, C.H.** (1994) A preliminary literature list and review for salt marsh restoration as applied to Eagle River Flats, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 333–340.

Remediation actions for removing or covering WP particulates in Eagle River Flats will result in impacts and changes to salt marsh habitats. There is a need to predict and understand how these impacts will change the functions and values of these habitats and how lost values can be restored or mitigated. Treatability studies presented in this report involve sublimation of WP particles through drying of contaminated sediments; such drying could be accomplished by dredging or draining contaminated ponds. These actions could result in fairly drastic alterations of pond habitats. These habitats may therefore permanently or temporarily lose desirable values or functions, depending on natural recovery rates or active attempts at restoration. The purpose of this review is to determine if methods and techniques for restoration exist and how other salt marshes have responded to major alterations such as draining or dredging.

(This is a truncated version of the *Introduction*. No abstract was provided.)

**Racine, C.H.** (1995) Analysis of the Eagle River Flats white phosphorus concentration database. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 255–276.

The purpose of this study was to maintain, update, and analyze the WP concentration database for ERF. Maps showing the location and concentrations of samples are presented in a Map Atlas appendix to this report. Over 1900 WP concentration measurements have been made on sediment and water samples from ERF since 1991. During 1994 about 500 sediment and 90 water samples were collected and analyzed for WP. Sampling in 1994 was concentrated in tidal gullies, experimental pens, and remediation test sites. AEHA collected samples at a wide range of ponded areas and also sampled gullies and the Eagle River in conjunction with invertebrate sampling.

Of the 1845 sediment samples that have been collected from ERF, no WP was detectable in about 65% of the samples. Of the positive samples only 15% had concentrations above 1 $\mu$g/g; therefore, where WP contamination occurs in ERF pond sediments, it takes the form of very low WP concentrations (<1 $\mu$g/g) over fairly extensive pond bottom areas. These areas are punctuated with small localized "hot spots" of much higher concentrations (>1 $\mu$g/g).

No new areas of WP contamination were identified in 1994. One exception was the finding in November (following a flood tide) of low levels of WP in pond sediments adhering to the bottom of rafted ice blocks. There is still little or no evidence for WP contamination in sediments from mudflats and in tidal gullies. In 1994 high levels of WP continued to be found in pond bottom sediments in Area C, on Racine Island, and in the Bread Truck Pond. Only low levels of WP contamination have been found in Area A ponds. Although a number of additional samples were collected in Areas B and D during 1994, no WP was found. The distribution of WP in ERF is closely correlated with the distribution of high crater density, indicative of past WP input.

When evaluating the degree of WP contamination of a site, the percent positive samples, the maximum concentration value, and the geometric mean are useful. However, analysis of WP concentration data sets from a range of different sites and scales shows very high levels of variability, making the use of parametric statistics difficult. Normalization of the data using natural log transformations and calculation of the geometric mean is useful, but a new sampling technique that would reduce the heterogeneity and better represent the WP concentration at a site is needed. The use of nonparametric statistics for WP concentration data may be more appropriate. One method to reduce variability involved stirring the water above the sediment and collecting a water–sediment slurry for analysis. This method was tried with marginal success.

Because of the high variability in WP concentrations at a site, it may be difficult or impossible to use WP sediment concentration data in risk assessments and for evaluating the effectiveness of remediation. Selective sampling of known hot spots before and after remediation may be useful. The use of sentinel or penned ducks combined with mortality measures (by telemetry and transect counts) after remediation may be important to evaluate the success.

Correlation between WP sediment concentrations, the presence of detectable WP particles, and mortality rates for mallard ducks placed in six experimental pens were fairly reasonable. It is likely that only the restricted "hot spots" with higher concentrations (1–3000 µg/g) contain particles sufficiently large (greater than 0.5 mm) to be selected by and cause acute toxicity to a feeding duck. Only 15% of the WP-positive sediment samples collected in ERF show concentrations above 1 µg/g. The fact that a relatively small percentage of the waterfowl that feed in ERF probably die from WP poisoning also supports the "hot spot" theory and agrees with our finding that less than 15% of all WP-positive sediment samples have concentrations over 1 µg/g. Only in sediment samples with concentrations above this level have we been able to find identifiable particles of WP. However, mallards died when placed in pens from which nearly 100% of samples had detectable concentrations of WP, all of which were less than 1 µg/g.

**Racine, C.H.** (1997) FY96 Eagle River Flats GIS database. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 101–103.

In 1996 the ERF spatial database was transferred to CH2M Hill for use in the preparation of the Remedial Investigation (RI) report, an important CERCLA document. As part of this transfer, an audit and QA/QC procedures were conducted on the database. In the RI document the GIS database was analyzed extensively to conduct an ecological risk assessment and thereby identify areas in ERF of highest risk to waterfowl. Of major importance to these conclusions were coverages developed and updated in 1996, including the Waterfowl Database, consisting of mortality transect data, telemetry data, and some census data from past years. The WP Database was also critical to this document and now contains about 2700 samples collected in ERF and analyzed for WP. Finally, the Landcover Database, showing crater density and the locations and distributions of ponds used by waterfowl, was critical to identifying high-risk sites. Other accomplishments in 1996 include transfer of the database to the USARAlaska GIS project, telemetry data analysis, and future planning of a remediation monitoring and evaluation database.

**Racine, C.H., and P. Berger** (1998) GIS remediation database for Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 115–127.

As the remediation of white phosphorus in ponds proceeds over the next several years, the GIS database will centralize the data needed to evaluate the success of the effort and monitor changes in the environment on ERF. The database design is described and diagrammed. Ongoing analysis of radiotelemetry data will help analyze movements and mortality. New coverages for remediation actions, white phosphorus composite sampling, and planted particles were added during FY97. New remote sensing methods for determining which ponds have drained and for monitoring gully advancement are described in another section of this report.

**Racine, C.H., and M. Brouillette** (1995) Appendix A: Eagle River Flats map atlas. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 633–698.

Beginning in 1990, when CRREL determined that WP was the cause of waterfowl mortality in Eagle River Flats, a strong effort was made to survey the precise location of all sample sites. During the period from 1991 to the present (1994), this practice has been continued and expanded to the locations of monitoring sites and remediation pilot studies. In 1992, a Geographic Information System (IDRISI) was purchased and surveyed sample location information entered. In 1993 the data were placed in a new GIS system (ARCINFO) operated by M. Brouillette. This has facilitated the production of the high-quality maps presented here.

This map atlas is produced to document the location of all sample, monitoring, and remediation test sites in Eagle River Flats during studies between 1991 and 1994. The database shows in map form the location and presence–concentration of WP in all the collected sediments and water samples. (About 2000 samples were collected and analyzed for WP between 1991 and 1994.) Because the distribution of WP particulates in ERF is patchy and localized, organism exposure to WP is also site specific and highly localized. These maps can be used to help designate and prioritize areas for remediation.

(This is a truncated version of the *Introduction*. No abstract was provided.)

**Racine, C.H., and M. Brouillette** (1995) Ecological inventory of Eagle River Flats, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 25–52.

Field studies, mapping, and evaluation of the terrain (vegetation, topography, soils, water bodies, and disturbance) in Eagle River Flats, an 865-ha estuarine salt marsh and artillery impact area on upper Cook Inlet, were conducted in order to better characterize the ERF ecosystem, to help evaluate white phosphorus distribution, persistence, and ecological risk, and to provide a baseline for evaluating and predicting the future effects of remediation.

Field transects from 100 to 1500 m long were positioned across the major environmental gradients and sampled at intervals of 20–40 m for vegetation, topography (elevation), soil texture, water bodies, and disturbance (craters). The results of this study and air-photo interpretation were used to describe, classify, and map into a GIS the derived terrain–vegetation units. These units were also evaluated in terms of their habitat use, potential to contain and store white phosphorus, and their susceptibility to disturbance.

Surface elevations decrease by 0.5 to 1 m over a distance of about 500–1000 m back from the levees (at about 5.0-m elevation) along Eagle River into the pond / marsh zone at elevations of 4.0–4.6 m. The surface materials contain increasing fractions of clay-sized sediment from the levees into the ponds. Ponds with their bottom elevations below 4.5–4.7 m are permanently flooded–saturated and therefore the opportunity for natural attenuation of WP is unlikely. Dredging of the permanent ponds and marshes will remove most food items (seeds, invertebrates, and pondweed) and create more areas of open water.

Seven large landscape zones and 15 landform–vegetation classes were recognized, described, and mapped. Three zones (mudflat / gully, pond / marsh, and interior lowland) account for about 80% of the area of ERF. Other zones include riverine, border, coastal, and interior sedge meadow. A diverse range of vegetation types was classified and mapped, including barrens, halophytic wet meadows, marsh, brackish pondweed, sedge meadows, sedge bog, marine alga, scrub-shrub, and woodland. The flora of ERF consists of about 57 species of vascular plants, many of which occur in other Cook Inlet salt marshes. Plant species diversity is low except on a few higher relict ridges. Water bodies include intermittent ponds, rivers, permanent ponds, wet swales, tidal gullies, and drainageways. Bird species use is described for each of 12 habitat classes.

**Racine, C.H., P. Robinson, and J. Mullen** (1996) The Eagle River Flats spatial database. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 365–387.

This report describes the construction, use, and contents of the Eagle River Flats (ERF) GIS (geographic information system) database. The purpose of the database is to help make and document decisions concerning the designation of WP "hotspots" to be treated, the selection of treatment methods to be used, and the success of the cleanup effort. At present, the database is designed primarily to identify hotspots to be treated, using a waterfowl risk assessment–exposure framework. The database includes both GIS coverages in ARC / INFO and ARC VIEW, or both, and tabular spreadsheet data residing on computers in the CRREL ERF GIS lab. Sharing of this database with other groups was initiated in an attempt to conduct analyses and make crucial decisions concerning hotspot location and waterfowl risk assessment. The database was originally started in 1993 to show the features of ERF (waterbodies, tidal gullies, vegetation–habitat, boundaries, and craters) in relation to sediment and water samples, collected and analyzed for white phosphorus.

Much of the ERF GIS database effort during 1995 centered on the entry of waterfowl census, telemetry, and mortality data, collected over the past 3 to 4 years, to locate areas that waterfowl use and therefore exposure to WP (if present) is high. In addition, the database for WP samples was updated and rebuilt to make analyses easier. The primary coverages include ERF natural features, white phosphorus sampling data (for 2549 point samples), waterfowl mortality sampling (1254 carcass point locations monitored in 1992, 1993, 1994, and 1995), waterfowl population aerial and ground censuses (1994 and 1995), and radio-telemetry locational data for 127 radio-collared ducks, 14 eagles, and 20 shorebirds (1993, 1994, and 1995). About 39 primary coverages compose the master ERF GIS database.

Secondary coverages are also listed and may be important for future decisions at ERF. These include sedimentation–erosion studies, remediation tests, water quality and weather monitoring sites, and GPS ground-truth data. To help accomplish the selection of appropriate cleanup method technologies, researchers will need to supply criteria for determining where their technologies would and would not work. The third decision concerning evaluation of cleanup success involves the design of endpoint criteria to be entered into the database.

**Racine, C.H., B. Tracy, and P. Berger** (1998) Mapping and classification of intermittent and permanent ponds on Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 101–114.

If ponds with sediments that become desaturated in some years can be identified, it is cost effective to allow natural attenuation of white phosphorus to occur in these ponds, rather than actively dredge, pump, or drain. In 1993, about 350 ponds covering 125 ha were photointerpreted from orthophotos and digitized into a GIS database (ARC/INFO). Each pond was classified as permanent (ponds that do not dry out in any year) or intermittent (ponds that dry up in some years and where white phosphorus could potentially sublime). In mid-July 1997, we conducted a field accuracy assessment of this classification by visiting 35 mapped ponds during a "dry period" (i.e. 60+ days without a flooding tide) and determined how much of the surface was flooded, as well as other pond characteristics. The results showed an 86% accuracy in the original classification, well within the Federal Geographic Data Center's level of acceptance. In addition, we tested the use of digital multispectral video (DMSV) images for automated mapping of permanent and intermittent ponds and for monitoring pond drying and other conditions. Classified DMSV imagery was also used successfully to monitor both headward and lateral gully erosion between 1993 and 1997.

**Racine, C.H., and M.E. Walsh** (1994) WP in sediment. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 153–184.

To characterize the distribution and concentrations of WP in Eagle River Flats, over 2000 sediment samples have been collected and analyzed from a range of habitats, including ponds and marshes, mudflats, and distributary channels, over the past 3 years. Surface sediments (the top 5 cm) were hand-scooped from the bottoms of ponds for analysis. In 1993 a composite pond sampling technique and field screening method were successfully tested. Concentrations of WP in sediments ranged from less than the detection limit of 0.00088 µg/g to over 3000 µg/g. The concentration frequency distribution for surface sediment samples follows a log-normal distribution. Most sample concentrations are in the range of 0.001–0.01 µg/g, a relatively low level given that the lethal dose to a mallard is in the range of 6000 µg.

Initial screening for WP in the sediments of seven pond areas was conducted in 1991 at 25-m intervals along transects through each pond area; two of the seven pond areas (Area C and the Bread Truck Pond) were identified as being highly contaminated with WP (over 50% of the samples were positive, and the concentration of at least one sample was over 1 µg/g). Another pond area (Area A) was only lightly contaminated. Indicator conditions of WP presence (crater cover, carcass density, and water depth) were mapped and used as an aid in selecting new areas for additional sampling. During 1992 and 1993, additional sampling of Area A failed to show WP hot spots, despite the presence of carcasses. A new, highly contaminated pond area on Racine Island was identified in 1993 on the basis of the large numbers of duck carcasses found there.

About 100 sediment samples from mudflats (without standing water but with high crater cover) were collected and showed less than 10% positives and low concentrations. To see if WP is being transported out of the two contaminated ponds, 87 sediment samples were collected along the lengths of four distributary channels; only two tested positive for WP (in pools at the head of these channels).

**Racine, C.H., M.E. Walsh, C.M. Collins, D.J. Calkins, and B.D. Roebuck** (1991) Waterfowl mortality in Eagle River Flats, Alaska: The role of munition compounds. CRREL Contract Report to the U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland USATHAMA Report No. CETHA-IR-CR-991008.

For more than 10 years, the cause of catastrophic waterfowl mortality in Eagle River Flats (ERF) has remained a mystery. Eagle River Flats is an estuarine salt marsh on upper Cook Inlet that has been used for over 40 years as an Army artillery impact area on Ft. Richardson. During the 1990 spring and fall waterfowl migration period in ERF, CRREL and the Dartmouth Medical School examined the hypothesis that contamination with munition compounds from test firing is the cause of this mortality. Firing into a wetland such as ERF could result in incomplete combustion and the deposition of munition residues in the sediments. Since dabbling ducks (teal, pintails, and mallards) and swans (trumpeter and tundra), which feed in the bottom sediments of shallow ponds, are the major victims, we assumed that the toxin is probably located in these pond sediments. Based on our 1990 field and laboratory studies, white phosphorus from past firing of smoke-producing projectiles has been identified as the causative agent of waterfowl mortality in ERF.

To determine if munition compounds are the cause of waterfowl mortality in ERF, our studies were designed to: 1) review the types, amounts, and toxicity of munitions used in ERF in the past, 2) determine if munitions are present in ERF sediments, 3) document the circumstances of waterfowl death in ERF in terms of feeding and symptomatic behavior, 4) collect tissues from ducks and swans observed to die in ERF for chemical and histopathological examination, 5) feed munition compounds found in the ERF sediments to laboratory ducks and document the effects, and 6) measure estuarine salt marsh conditions that might influence the storage or movement of munition compounds.

Sediments and water, as well as tissue from dead waterfowl, were collected in Eagle River Flats during the spring (May) and fall (August–September) 1990 waterfowl migrations. Over 250 sediment and water samples were collected and analyzed (93 sediment and water samples in the spring and 172 sediment samples in the fall). Collection sites were precisely located by surveying, and a number of water and sediment (salinity, pH and redox potential) and vegetation parameters were measured at each collection site. This information was managed and displayed using a Geographical Information System (GIS). During May, 93 water and sediment samples, obtained mainly from explosion craters, were tested for TNT or RDX with a field test kit developed at CRREL. Neither of these two compounds were detected in these samples; however, in the laboratory high-performance liquid-chromatography (HPLC) techniques revealed the presence of 2,4-DNT (a nitroaromatic compound) in three samples adjacent to an explosive ordnance disposal (EOD) area. Intensive sampling of this area in the fall (172 sediment samples) revealed that 62 samples in a large area of tall sedge marsh adjacent to the EOD were contaminated with 2,4-DNT (up to 62.9 mg/g), probably from improper disposal of 2,4-DNT-containing propellant grains on the EOD pad.

In addition, a single sediment sample, collected near the EOD area of 2,4-DNT contamination, produced smoke when the collection jar was opened in the laboratory. When this sample was analyzed by gas chromatography–mass spectroscopy (GCMS) techniques, the presence of white phosphorus was confirmed. Subsequent GCMS analysis of 15 additional sediment samples collected in the fall revealed the presence of white phosphorus (WP) in eight, with half of these samples from a shallow pond used by waterfowl.

The behavior of dying ducks observed and videotaped in ERF during the fall migration included increased drinking, lethargy, head rolling, and violent convulsions. Tissue samples were also collected from stricken ERF waterfowl during the fall migration and analyzed for white phosphorus. A laboratory toxicity study was conducted in which acute dosages of the two different munitions compounds (white phosphorus and 2,4-DNT) found in ERF were fed to domestic mallard ducks and their behavior, tissues, and blood analyzed. Based on the following evidence from these field and laboratory studies of white phosphorus and 2,4 DNT, white phosphorus is the prime candidate for the causative agent of waterfowl mortality:

- The lethal acute dose of white phosphorus to laboratory ducks is only milligrams per kilogram of body weight, whereas the lethal dose for 2,4 DNT is on the order of 1 g/kg. Thus, ingestion of small amounts of white phosphorus seems more probable than large quantities of 2,4-DNT.
- White phosphorus was found in all waterfowl carcasses (seven ducks and five swans)

collected in ERF but in none of five wild ducks collected from Susitna Flats, a similar salt marsh over 30 km distant from ERF.

- The behavior of laboratory ducks dosed with white phosphorus was consistent with that of sick ducks in ERF, while the behavior of laboratory ducks dosed with 2,4-DNT was not similar to that observed in the field.
- The concentrations and distribution of white phosphorus in duck tissues was similar in both laboratory ducks dosed with white phosphorus and in dead ducks collected in ERF.
- High methemoglobin blood levels, a symptom of 2,4-DNT poisoning known and seen in the laboratory toxicity studies and indicated by a very brown coloration of the blood, was not obvious in any of the ERF ducks autopsied in the field. All blood of field-autopsied ducks was bright red.
- In ERF, 2,4-DNT was found only in a tall sedge marsh, a habitat not used by feeding ducks, whereas limited sampling for white phosphorus showed occurrence in a shallow pond used intensively by waterfowl.

Since white phosphorus is extremely reactive and quickly oxidized or burned in the presence of oxygen, various scenarios describing a mechanism by which unburned white phosphorus entered and was stored in the salt marsh sediments are presented. Although firing into ERF ceased in February 1990, waterfowl continued to die during the spring and fall, indicating that white phosphorus is persistent. Frequent flooding, combined with heavy suspended clay sediments, results in burial of white phosphorus under anaerobic conditions conducive to long-term storage. Measured redox potentials in salt marsh sediments were particularly low (< –200 mV) in the bottoms of ponds where the dabbling ducks feed, confirming the anaerobic nature of the sediments. Based on this information, we feel that the munition white phosphorus is the major cause of mortality in ERF.

**Racine, C.H., M.E. Walsh, C.M. Collins, D. Lawson, K. Henry, L. Reitsma, B. Steele, R. Harris, and S.T. Bird** (1993) White phosphorus contamination of salt marsh sediments at Eagle River Flats, Alaska. Part II. Remedial investigation report. CRREL Contract Report to the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland AEC Report No. ENAEC-IR-CR-93063.

*Summary 1992*

In Eagle River Flats there are a large number (75–100) of small to large open-water ponds where waterfowl feed; these cover a total area of about 70 ha (175 acres), or 8% of ERF. Based on our sampling and white phosphorus (WP) analysis of over 1000 sediment samples from these ponds, the major contamination and hypothesized source of most of the waterfowl poisonings in ERF is in two ponded areas (Area C and the Bread Truck Pond), covering areas of about 18 ha (45 acres) and 6.5 ha (16 acres), respectively. Sediment cores 20–30 cm deep from the bottom of the contaminated ponds showed that WP can be buried in the sediments to depths of 30 cm (1 ft) and probably more. WP contamination of mudflat sediments adjacent to the contaminated Area C and Bread Truck Ponds was found in 6 out of 56 samples.

A simple and repeatable index of waterfowl mortality by which to evaluate future remediation efforts was developed and applied over the past three migration periods using permanent transects through the ponds and in the adjacent woodlands. No decline in mortality levels were detected from August 1991 to August 1992.

WP contamination of ERF sediments involves particles of a wide range of sizes from less than 0.15 mm up to 3.5 mm. Other abundant items of similar sizes on which waterfowl feed in the sediments include insect larvae and seeds. Moreover, each sediment sample obtained from different pond locations appears to have a unique abundance and range of WP particle sizes. In the laboratory, disturbance of contaminated sediments containing large numbers of these smaller particles (<0.15 mm) can result in their suspension in the water column for up to 2 hours. Surrogate sampling suggests that such suspended WP particles may be transported out of ponds into distributary channels connecting with the Eagle River.

Sedimentation in the summer of 1992 (28 May–22 Sept) ranged from 4 to 30 mm, with the highest in the ponds (25–30 mm) and the lowest on the levees adjacent to Eagle River. Sediments originate from the Eagle River and from tidal influx from Knik Arm. Resuspension and redeposition of pond bottom sediments occurred at a rate of about 15 mm over the summer season. Processes included wind waves and sediment-feeding birds. Headwalls of gullies are actively eroding by undermining and collapse; recession rates ranged from about 0.5 to 2.0 m.

Three treatability studies were conducted, and the results presented in the EPA-CERCLA format. Geotextiles are an effective method for reducing the exposure of waterfowl to WP poisonings. Chemical oxidation of WP in heavy ERF sediments is effective under certain conditions, but there is no simple means of mixing of the oxidant into the heavy sediments in situ. Drying of wet contaminated sediments can eventually oxidize WP but only at very low moisture levels, which may be unattainable in the field. Drying, however, may be a suitable treatment for dredge spoil.

The large database being assembled on the contamination, effects, and environment of ERF was placed into a geographic information system. This permits the rapid generation of maps and displays as well as monitoring of future changes and related remediation actions.

*Summary 1990–1992*

In 1990 particles of white phosphorus (WP) in pond-bottom sediments were shown to be the cause of the mortality of thousands of waterfowl, documented since 1982 at Eagle River Flats, an 865-ha estuarine salt marsh and artillery range at Ft. Richardson Alaska. WP enters the pond sediments as a result of detonation of smoke projectiles and is the first documented case of WP wildlife poisonings in a U.S. Dept. of Defense Artillery Training Area.

*Mortality monitoring.* A simple and repeatable index of waterfowl mortality by which to evaluate the success of future remediation efforts was developed and applied during three migration periods using carcass and feather pile counts along permanent transects through ponds and in the adjacent woodlands.

There is differential susceptibility to poisonings among the various species of dabbling ducks feeding in ERF ponds. Green-winged teal, northern pintail, and mallards are frequently found dead, while northern shovelers and American wigeon appear to be less susceptible. In addition to dabbling ducks and swans (waterfowl), several species of shorebirds are dying from WP poisoning.

*WP forms and distribution.* There are a large number (75–100) of small to large ponds covering a total area of about 200 acres of ERF. However, our analysis of over 1000 sediment samples for WP suggests that the major contamination and hypothesized source of most of the waterfowl poisonings in ERF occur in two ponded areas covering a combined area of about 60 acres.

WP occurs in the sediments as soft, waxy particles of a wide range of sizes from less than 0.15 up to 3.5 mm. The number of particles in the various size classes from small to large varies greatly from one sediment sample to the next or from place to place within a pond. Disturbance of contaminated sediments (from traffic, wind, feeding) results in the suspension of WP particles in the water column above contaminated sediments, particularly where the majority of particles are in the small size ranges (0.15 mm or less). Sediment cores 20–30 cm deep showed that WP can be buried in the sediments to depths of 30 cm and probably more.

Waterfowl feeding in the pond bottom sediments ingest these particles as food items (or possibly as gizzard grit). The ingestion by a 1-kg duck of a single 1-mm particle (1.8 mg) can be fatal.

*WP transport.* Surrogate sampling suggests that suspended WP particles may be transported from contaminated ponds into distributary channels connecting with the Eagle River.

Although WP was not found in gizzards of 305 waterfowl shot in other Cook Inlet salt marshes, WP was found in the gizzards of four out of six teal shot on the wing in ERF and in two carcasses collected less than 0.5 miles from ERF, indicating that once waterfowl ingest WP they are capable of flying a limited distance.

Decomposing carcasses of WP-poisoned ducks likely redeposit WP into the sediments.

*Food chain risks.* Predators in ERF, such as eagles, ravens, and gulls, are ingesting WP-contaminated duck tissues and are likely at risk. The tissues of a dead eagle and a seagull egg contained WP.

Human health risks through consumption of ducks shot in nearby Cook Inlet marshes were found to be minimal based on the analysis for WP in over 300 hunter-harvested duck gizzards collected in September 1991.

*Treatability studies.* A test detonation of a high-explosive projectile charge in WP-contaminated ERF sediments did not reduce WP concentrations and likely exacerbated the contamination problem. Geotextiles are an effective method for reducing the exposure of waterfowl to WP particles. Chemical oxidation of WP in heavy ERF sediments is effective under certain conditions, but there is no simple means of mixing of the oxidant into the heavy sediments in situ.

Drying of wet contaminated sediments can eventually oxidize WP but only at very low moisture levels, which may be unattainable in the field. Drying, however, may be a suitable treatment of dredge spoils.

*ERF environment.* As an estuarine salt marsh, Eagle River Flats is an extremely important, productive, and dynamic ecosystem that supports a broad range of habitats and species (over 50 bird species were observed to use the area) and involves complex physical, chemical and biological processes.

A geographic information system, combined with remote sensing techniques, was developed to manage and display the large amount of sediment sample data and other environmental–habitat baseline conditions important for future cleanup efforts in ERF.

The pond-bottom invertebrate fauna and seed banks have been characterized.

**Racine, C.H., M.E. Walsh, C.M. Collins, S. Taylor, B.D. Roebuck, L. Reitsma, and B. Steele** (1992) Remedial investigation report for white phosphorus contamination in an Alaskan salt marsh. CRREL Contract Report to the U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland USATHAMA Report No. CETHA-IR-CR–92004.

In 1990 personnel from CRREL and Dartmouth College proved that an annual waterfowl dieoff at Eagle River Flats (ERF), an Alaskan salt marsh, was attributable to the ingestion of highly toxic particles of white phosphorus (WP), which entered the bottom sediments of shallow ponds as a result of past artillery training with WP-containing incendiary munitions. During 1991, the 1990 hypothesis that WP is the cause of waterfowl mortality in ERF was strengthened by: 1) the positive identification of WP in the tissues of an additional 38 dabbling ducks, 4 swans, 9 shorebirds and 1 eagle (all 63 bird carcasses from ERF analyzed during 1990 and 1991 have tested positive for WP); and 2) the finding of WP in an additional 116 sediment samples collected from the bottom of shallow waterfowl feeding ponds.

During the 1991 spring and fall waterfowl migration periods, intensive sediment sampling and avian field studies were conducted around constructed blinds in the six waterfowl feeding pond areas where dabbling ducks feed and where most carcasses have been found. Sediment and tissue samples were analyzed for WP in a nearby field laboratory. Experiments with contaminated sediments and WP were also conducted in the laboratory at CRREL.

Reliable analytical methods (solvent amounts, extraction times, and sub-sample size) were developed to extract WP particulates from ERF sediment samples. In the field, one 20-$cm^3$ extracted subsample from each 500-$cm^3$ jar containing the sediment sample provided a reliable determination of the presence or absence of WP but is less reliable in representing the actual concentration of WP in the total 500-$cm^3$ sample.

Over 400 pond-bottom surface sediment samples were collected at 25-m intervals along transects in the six waterfowl feeding pond areas, representing only 5% of the total area of ERF. The bottom sediments of two of the six sampled waterfowl feeding ponds contained a high percentage of WP-positive samples. In addition the WP concentrations of samples from one of these ponds (Bread Truck Pond) were significantly higher than those from the other ponds. Area C and the Bread Truck Ponds, covering an area of about 15 ha (37 acres), are hypothesized to be the major sources of WP duck poisoning in ERF. Over 350 hours of observations of dying ducks and predation on them also supports this hypothesis.

The bottom sediments of the two contaminated ponds in ERF likely contain a large number of very small WP particles (<0.1 mm) and a small number of much larger particles (1 mm). The larger particles could provide a lethal dose (around 0.25 mg) for a small duck such as a green-winged teal. The very small WP particles in the sediments can become suspended in the water column and could provide another source of exposure for waterbirds, fish, or plankton. WP poisoning of non-waterfowl species, particularly phalaropes, was documented; however, extensive areas of mudflats used by migrating shorebirds in ERF were not sampled and could contain WP. High rates of predation and consumption of WP-containing duck carcasses by bald eagles, herring gulls, and ravens indicate that these species are at risk. WP was detected in the tissues of a dead bald eagle found in ERF.

Evidence suggests that WP is transported within (and to a very limited extent, out of) ERF in birds that have ingested WP but can still fly. Dead waterfowl found in ponds without detectable WP could have ingested the WP in either Area C or the Bread Truck Pond and flown to and died in one of these other areas. Human health risks through consumption of ducks shot in nearby Cook Inlet marshes were found to be minimal; there was no detectable WP in over 300 hunter-harvested duck gizzards collected in September 1991.

The mechanisms by which WP particles enter the pond sediments are unknown but could include smoke projectile air bursts or ground bursts, as well as leakage or subsurface explosion of duds. In the laboratory a burning particle of WP dropped into water contained a significant amount of unoxidized WP. Evidence is also presented that WP may enter the sediments as a result of the decomposition of a WP-poisoned duck carcass.

A literature review of WP remediation techniques showed that ERF is the first documented case of a U.S. artillery training area contaminated with WP particles. In cases of WP contamination from wastewater, WP was oxidized by exposure to oxygen or chemical oxidants. In our laboratory, air-drying and aeration of ERF sediments reduced WP concentrations after several days. Oxidation using hydrogen peroxide accelerated WP oxidation. In ERF a test explosion simulating the detonation of a 105 howitzer projectile was shown to redistribute, not oxidize, WP particles; thus, resumption of summer firing is not a remediation option. A method of monitoring waterfowl mortality in permanent transects was developed and tested and should be used to establish a baseline mortality index for evaluating the success of future remediation.

**Reitsma, L.R., and B.B. Steele** (1994) Waterfowl use and mortality at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 205–226.

The objective of the waterfowl mortality study was to assess the relative amount of waterfowl mortality in order to detect year-to-year changes as WP exposure decreases through remediation efforts. Our approach over the past 3 years (1991–1993) has been to count feather piles and carcasses on sample areas of ERF and in the surrounding woods and to extend the total area sampled to more accurately estimate total mortality and detect potential new areas of high mortality.

We found that overall mortality has varied annually. We now have complete and comparable data for 1992 and 1993, and we found that mortality was much lower in 1993 than in 1992. This lower mortality is mostly a reflection of the fact that fewer waterfowl used ERF in 1993. However, the mortality was proportionally similar in both springs but significantly lower in August 1993 compared to August 1992. This decrease in mortality could be the result of lower WP availability, differences in sample size, human disturbance, or a combination of these factors.

We found evidence of at least three, most likely four, eagle carcasses in the woods and on the Flats. Because this was the first systematic search of the woods surrounding ERF, the results suggest that WP contamination may have a greater impact on bald eagles than previously thought, although none of these carcasses had any analyzable tissues.

**Reitsma, L.R., and B.B. Steele** (1995) Waterfowl use and mortality at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 289–320.

The main objective of the waterfowl mortality work in 1994 was to continue measuring mortality with the standardized method established in 1991 and further revised in 1992. In addition, habitat use studies were conducted for input into the IRAM (Integrated Risk Assessment Model) described below. Photo-identifications of scavenger species that remove WP-poisoned carcasses from ERF were also conducted.

Carcasses were counted on transects in Areas A, C, the Bread Truck Pond and Racine Island during the spring and fall migration periods. We also counted feather piles on transects in the bordering woods in the spring. These feather piles represent carcasses removed from the Flats by scavengers (mostly eagles). Mortality was calibrated by daily censuses to quantify use of ERF by migrating waterfowl over the same period. These data were used in an ANCOVA (Analysis of Covariance) to analyze for significant differences in mortality between years. The mortality rate in the spring of 1994 was significantly lower than in the springs of 1993 or 1992. The mortality rate in fall 1994 remained lower (as in fall 1993) than in fall 1992. Reasons for these differences are discussed. Waterfowl habitat use was quantified by conducting simultaneous observations of waterfowl behavior from two to four locations in spring and fall. These observational data can be used to assess habitat preferences and to calculate risk using the Integrated Risk Assessment Model described below. Preliminary photographs at carcass-baited trip mechanisms wired to cameras in the woodland bordering ERF indicate that coyotes and northern harriers may be exposed to WP through secondary contact with duck parts left in the woods by predators and scavengers. The severity of this contact was not determined.

**Roebuck, B.D.** (1996) Analysis of white phosphorus in biota at Eagle River Flats, 1995 field season. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 175–178.

Tissues from animals found dead on Eagle River Flats during 1995 were analyzed for white phosphorus to help confirm the cause of death. A total of 31 animals was examined: 30 birds and 1 coyote. The coyote did not contain WP. Of the birds, approximately 20% did not have WP in their tissues. These birds (six in total) are either individuals that died of other causes (some of which may be natural causes), or individuals in whom the WP dissipated prior to their ultimate death.

**Roebuck, B.D., and S.I. Nam** (1995) Toxicological properties of white phosphorus: Comparison of particle sizes on acute toxicity and the biotransfer of white phosphorus from hen to eggs. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 235–254.

To date, all of the published data on the toxicity of WP in ducks have been based on WP dissolved in oil or in tissues. The present studies were therefore undertaken to assess if toxicity of WP differed between WP dissolved in edible oil and particles of size classes representative of the particles found in the sediments at ERF. The distribution of WP in the GI tract was also determined in both lab and wild birds to assess the risk of WP to predators. Detailed observations were also made to identify a time point that sick birds could be therapeutically treated. Cholinesterase activity was also measured to determine another mode of treatment. Studies were also undertaken in egg-laying chickens to further explore the biological fate of absorbed WP.

Toxicity from dissolved and particulate WP was very similar at a dose of 12 mg/kg. The time of death in minutes (mean ± std. dev.) was 250 ± 110, 300 ± 100, and 230 ± 60 for the dissolved WP, small particle, and large particle groups, respectively. The times of death for all three treatments were not statistically different from each other. In laboratory ducks, the quantity of WP in their digestive tracts varied between treatment groups. The highest quantity of unabsorbed WP (19% of given dose) was in the GI tract of small-particle-dosed ducks. The dissolved WP was not appreciably retained by the gizzard and reached lower portions of the digestive tract. Ducks from DWRC and ERF all had varying levels of WP distributed in their GI tract. The short latent period between the first signs of intoxication and convulsion argues against effective treatment of sick birds. And finally, the lack of cholinesterase inhibition indicates that antidotes for anti-cholinesterase poisoning would not be effective.

**Rossi, C.** (1995) Hazing at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 423–428.

During parts of May, September, and October of 1994, Animal Damage Control (ADC) continued efforts to keep migratory waterfowl from being poisoned by white phosphorous in ERF. The work involved the use of a variety of hazing methods, including propane cannons, scarecrows, mylar tape, as well as eagle effigies and electronic guards, and on-site personnel with shotguns and skyrockets. Activities were confined to discrete, limited areas within ERF, with other less-contaminated areas remaining as undisturbed sanctuaries.

In spite of a number of deviations from the norm in 1994, ADC's hazing operation was quite successful. NEILE's mortality data indicate low waterfowl mortality during active hazing operations. In one case waterfowl began using an unhazed contaminated area and ADC hazing operations were immediately implemented there. The effective protection of waterfowl was further enhanced by a contingency provision in the 1994 proposal that allowed ADC's operations to continue until all of the contaminated areas had frozen over (regardless of the date). This contingency provision will be proposed again for the 1995 season.

**Rossi, C.** (1996) Hazing at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of* *white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 197–204.

Hazing of waterfowl from ponds contaminated with white phosphorus was conducted during both the spring and fall migrations. The hazing operation was successful, as ADC observations, DWRC telemetry work, and waterfowl surveys by NBS and NEILE all indicated a dramatic decrease in waterfowl numbers in hazed areas compared with those of unhazed areas on ERF.

**Rossi, C.** (1997) Report of USDA-APHIS-Animal damage control for the U.S. Army at Eagle River Flats, April–October 1996. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 31–34.

From 15 April to 31 May 1996, USDA–Animal and Plant Health Inspection Service (APHIS)–Animal Damage Control (ADC) continued efforts to keep migratory waterfowl from being poisoned by white phosphorus in the Eagle River Flats (ERF) impact area at Ft. Richardson, Alaska. With only minor exceptions, ADC employed the same techniques that have proven to be successful in previous seasons. Hazing methods included propane cannons and visual scare devices, such as scarecrows and mylar tape. Additional static devices included eagle effigies and an electronic guard. However, ADC increased its emphasis on vigorously harassing the birds while they were still airborne over the protected areas. Waterfowl are more difficult to deter from an area after they have landed. Two ADC personnel walked or canoed through the areas of concern to service the devices and deter birds that had landed or were attempting to land in critical areas. Personnel used 15-mm pyrotechnics, shell crackers, and 20-in. skyrockets to frighten birds from areas of concern. From 15 April to 31 May, a total of 253 staff hours were expended in the field hazing a total of 1575 ducks and 10 Canada geese. There were no waterfowl moralities found by ADC personnel during the spring of 1996. In the fall, hazing was delayed until 23 September to allow researchers to monitor duck movements, marsh use, and mortality independent of hazing activities. Owing to the more stringent safety requirements, all access into ERF for hazing was to be done by hovercraft. However, by the time the hazing operation was to begin, only one of the four hovercraft available was even partially functional. Because of the lack of functional hovercraft from 23 September to 26 October, no waterfowl were hazed by ADC personnel. In excess of 100 staff hours and considerable funds were expended repairing hovercrafts.

**Rossi, C.** (1998) Report of USDA-APHIS-Wildlife Services for the U.S. Army at Eagle River Flats, April-October 1997. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 37–40.

During 1997 USDA–APHIS–Wildlife Services (WS), formerly Animal Damage Control, continued efforts to keep migratory waterfowl from being poisoned by white phosphorus in the Eagle River Flats (ERF) Impact Area. From 21 April to 31 May 1997, a total of 945 ducks and 30 Canadian geese were hazed at Eagle River Flats by five WS personnel. A total of 613 staff hours were expended in the field over 41 days of hazing. There were no waterfowl mortalities found by WS personnel during the spring of 1997. Several standard hazing methods, including propane cannons, visual scare devices, such as scarecrows and mylar tape, and eagle effigies, were used in Area A, Racine Island, C Pond, Lawson's Pond, and Bread Truck Pond to deter waterfowl from using the area. To augment the effectiveness of these static devices, WS personnel used 15-mm pyrotechnics, shell crackers, and 20-in. skyrockets to frighten birds from areas of concern.

During the fall of 1997, WS personnel essentially remained on standby, monitoring swan activity in the hot areas and assisting USDA-APHIS National Wildlife Research Center researchers with hovercraft support to recover transmitters from duck mortalities. Very few static deterrent devices were deployed in fall 1997. Late in the fall, a few propane cannons were deployed in Area A, when two swan mortalities were discovered there. From 23 September to 26 October 1996, in excess of 280 staff hours were expended monitoring the hot areas for swan activity, as well as transferring and repairing hovercrafts. Two swan mortalities were recovered by WS personnel during the fall of 1997.

**Sparling, D.W.** (1994) Invertebrates and fish. In *Interagency expanded site investigation: Evaluation of* *white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 259–266.

Nine taxa of macroinvertebrates were collected with dip nets in four ponded areas of ERF; the most commonly caught taxa including odonates, chironomids, and snails. Macroinvertebrates and fish were identified to species or genus, minced and mixed with isooctane for WP analysis. Because of quality assurance problems, the results were inconclusive and additional sampling of fish and invertebrates is needed.

**Sparling, D.W., R. Grove, and L. Comerci** (1994) WP poisoning of waterbirds in ERF. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 235–240.

Waterfowl found dead at Eagle River Flats displayed many of the same pathological signs as those that died during laboratory experiments. Liver necroses and foci, pancreatic and coronary petechiae, and hard rigor were observed in mallards, pintails, and green-winged teal. Brain cholinesterase appeared to be depressed in a few of the specimens collected in the field.

One tern had an enlarged liver compared to birds from a reference area. Two of five dowitchers and one Arctic tern had depressed brain ChE levels. Four of 18 mew gull embryos that were collected as eggs and incubated displayed mild to moderate hydrocephaly, and one mew gull and a herring gull embryo had crossed bills. The significance of these abnormalities and how they may relate to $P_4$ exposure are being investigated.

We collected 11 Arctic terns, 16 mew gulls, 5 lesser yellowlegs, 3 greater yellowlegs, 9 dowitchers and 8 northern phalaropes with a shotgun in ERF. Skin and crop contents of these birds were analyzed for WP. No detectable levels of $P_4$ were found in any bird.

Carcasses of 1 phalarope, 1 lesser yellowlegs, 3 pintails, 1 blue-winged teal, 14 green-winged teal and 14 mallards were collected in ERF. They were necropsied and analyzed for $P_4$. All of the ducks tested positive for WP, but the phalarope and lesser yellowlegs did not.

**Sparling, D.W., R. Grove, E. Hill, M. Gustafson, and L. Comerci** (1994) Toxicological studies of white phosphorus in waterfowl. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 133–151.

The acute median lethal dose for adult male and juvenile mallards exposed to $P_4$ dissolved in oil is 6.5 mg $P_4$/kg body weight (95% confidence interval = 5.8–6.9). Adult females were substantially less sensitive to $P_4$ than other age/sex classes. (The median lethal dose could not be calculated for this age/sex class.) Acute exposure to $P_4$ produced obvious clinical signs of 1) lethargy, ataxia, and mild leg trembling (these could either recover or progress into more advanced stages); 2) more severe trembling and a stereotyped bill movement; and 3) severe convulsions terminating in death. A characteristic very hard rigor mortis set in within 5–10 minutes after death in many cases. Some of the birds on repeated doses did not enter the convulsion phase and may have died from renal or liver failure. Gross necropsies and histopathology revealed that birds acutely dosed with >5.2 mg/kg $P_4$ frequently had foci, necrosis, and cellular vacuolations in the liver; damage to the proximal and distal convoluted tubules in the kidneys; and petechiae in the coronary fat band and pancreas. Brains of birds that died on dose often displayed mild to severe hemorrhaging or congestion. Duodena were also congested. Brain ChE activity was depressed in a dose-response manner in male mallards acutely exposed to $P_4$, but plasma ChE did not differ among doses. In contrast, the brain ChE of females did not differ due to dose, but there was a depression in plasma ChE activity at higher dose levels. Cholinesterase depression may be a useful method of detecting $P_4$ exposure, but additional tests are required before this method can be recommended.

The lowest-observed-effects level for acute mortality of mallards in this study was 4 mg/kg. However, organ damage was observed at the lowest dose used, 2 mg/kg.

White phosphorus levels in acutely dosed mallards that died during the study ranged from below detection to 1.776 mg/kg for fat, 0.959 mg/kg in skin, and 0.027 mg/kg in liver. We could not detect a linear relationship between $P_4$ residues and dosage. Birds that survived for a week had residue levels that were <1/100 of those in birds that had died at the same doses. White phosphorus in the fat of dead birds remains the most reliable indicator of exposure, but its instability diminishes its value to determine exposure in living birds.

Multiple daily exposures to $P_4$ over 4 days did not alter mortality above what would be expected by the acute levels of dosing solutions. There was a significant dose response in weight loss during treatment, probably attributable to malaise or inappetence, but this was transitory, and birds recovered their pre-treatment weights within 7 days after exposure.

**Sparling, D.W., R. Grove, E. Hill, M. Gustafson, and P. Klein** (1995) White phosphorus toxicity and bioindicators of exposure in waterfowl and raptors. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 201–234.

During 1994 researchers at the National Biological Service Patuxent Environmental Science Center conducted studies on seven tasks associated with risk assessment and monitoring of white phosphorus (WP) in Eagle River Flats, Fort Richardson, Alaska. These tasks included: 1) identification of biomarkers of WP in waterfowl; 2) preliminary studies on reproductive effects of WP in female mallards; 3) timing of uptake and loss of WP and the onset of pathology in mallards; 4) derivation of $LD_{50}$ and associated statistics for adult female mallards; 5) analysis of acute toxicity with pelletized WP; 6) examination of secondary toxicity in kestrels fed dosed poultry chicks; and 7) use of semi-permeable membranes (SPMAs) in monitoring WP in water and sediments.

*Identification of biomarkers for white phosphorus exposure in birds*

White phosphorus residues can only be measured in living tissues for a few days after exposure. Moreover, sublethal doses of white phosphorus can cause chronic or long-lasting effects. Therefore, identification of other physiological effects of exposure or bioindicators are essential for reliable assessment of risk to waterfowl and other species inhabiting areas contaminated with WP. In an initial study to identify potential biomarkers, mallards were dosed either once or twice with WP dissolved in oil. Before dosing and 3 days post each dose, a 5-mL sample of blood was taken and sent to a commercial veterinary diagnostic lab to determine changes in specific blood parameters. The blood factors that showed the greatest response to WP included blood urea nitrogen (BUN), BUN / creatinine ratio, lactate dehydrogenase, aspartate aminotransferase / alanine aminotransferase ratio, potassium, and glucose. Hematocrit, hemoglobin, chloride, sodium, and phosphorus also differed significantly due to treatment. These blood factors reflect the liver and renal damage identified by histopathological examination and hemolysis observed in pen studies. Additional analyses of other blood samples taken in laboratory and field situations are near completion and seem to support the above findings. At this early date, we suggest that reduced hematocrit and hemoglobin levels could be effective, reliable, and relatively simple screening techniques to identify birds that may have been exposed to white phosphorus.

*Preliminary studies on reproductive effects of WP in female mallards*

White phosphorus is a strong reducing agent, is lipid soluble, and appears to affect many physiological processes in mallards. Therefore, it has the potential of reducing reproduction and collecting in egg yolks, where it could affect developing embryos. A pilot study was conducted to determine if repeated handling of adult female mallards alone would impair reproduction or egg laying ability and to find effective dose levels prior to a more complete reproductive study. Four to five female mallards were gavaged with pelletized WP at either 2.6 or 1.3 mg / kg body weight daily for 5 days. Other groups were either given a placebo of distilled water or left alone except for daily egg collection (control). The placebo and control groups did not differ in number of eggs laid, fertility, or hatching success. Thus, we determined that daily handling did not appreciably alter reproduction in these birds. Two of the five females given 2.6 mg WP / kg body weight died within the first 5 days of treatment; another became lethargic and showed obvious signs of distress. All three surviving birds stopped laying eggs after two doses. One of these birds came back into sporadic lay 11 days after the last dose but did not produce fertile eggs. Four young hatched from these hens but from early eggs that probably escaped exposure to white phosphorus. One embryo had severe teratogenic deformities. At 1.3 mg / kg, one hen stopped laying after two doses and the other four birds laid erratically so that the average number of eggs laid was significantly fewer than either the placebo or control birds. Only nine young developed from eggs at the lower dose and only one of these hatched. Three embryos that failed to hatch had teratogenic deformities. Deformities included scoliosis, lordosis, submandibular edema, microphthalmia, and spina bifida.

*Timing of uptake and loss of WP and the onset of pathology in mallards*

The uptake and loss of white phosphorus from living tissues is important because of the possibility of secondary toxicity and human health perspectives associated with waterfowl hunting. Obviously, the risk of secondary exposure is related to the retention time of WP in tissues. Adult mallards were gavaged with a single dose of pelletized white phosphorus at 1, 2, and 4 mg/kg and then sacrificed at 3, 6, 12, 24, 96, and 240 hours after dose. Birds were necropsied for obvious organ damage and fat, liver, kidney, breast muscle, and brain were harvested for residue determinations. Of the 12 birds dosed at 4 mg/kg, 10 died within 24 hours after dose. The two survivors at this dosage were sacrificed at 240 hours; one appeared healthy and unaffected whereas the other had severe necrosis in approximately half of its liver and trace levels of WP in its fat. We surmise that the healthy bird had probably orally voided the pellet shortly after dosing. At 1 and 2 mg/kg, white phosphorus was assimilated within the first 3 hours after exposure, reached peak levels in fat within 6–12 hours after dose, and was at or near detection limits within 48 hours. Liver levels increased during the first 3 hours but rapidly dropped to detection levels by 24 hours after dose. Muscle and kidney levels were very low and essentially gone within 12 hours after dose. No WP was detected in brain tissue. Fatty livers appeared in a few birds as early as 3 hours after dose at the 2-mg/kg level.

*Adult female mallard acute toxicity*

Work conducted during 1993 allowed us to determine that the $LD_{50}$ of WP dissolved in oil for adult males was 6.4 mg/kg and that there was no difference between adult males and juvenile birds of either sex. However, adult females appeared to be much less sensitive to WP than the other age–sex classes and we were unable to confirm an $LD_{50}$ for this group. In 1994 we repeated our acute toxicity experiment with adult females at the same time of year (late July–early August) and breeding condition (after laying) as in 1993. We determined that the $LD_{50}$ for adult females was 6.8 mg/kg, which was not statistically different from that for adult males. However, adult females have a much shallower dose-response curve than adult males ($P$ <0.0001). This shallower slope makes predictions of mortality at specific dose levels less certain and also changes the risk assessment characteristics for adult females compared to males.

*Confirmation of acute toxicity and lowest observable effects level with pelletized white phosphorus*

Much of the work on acute toxicity of other compounds suspends the compound in a carrier such as water or corn oil. Our initial experiments used the same approach for comparability but waterfowl at Eagle River Flats are exposed to pelletized WP. Thus, we conducted a small test to compare the acute toxicity of pelletized WP to that dissolved in oil. Fourteen male mallards were given a single dose of WP at 6.5 mg/kg. Twelve died, which was greater than the expected number of seven ($P$ <0.05). Thus, pelletized white phosphorus is more toxic to adult male mallards than is white phosphorus dissolved in oil. Based on other studies that were conducted in 1994, we estimate that the $LD_{50}$ for pelletized WP is between 3 and 4 mg/kg. To determine the subacute effects of pelletized white phosphorus, we dosed 10 males at each of two levels, 2.4 and 3.4 mg/kg daily for 10 days. At 2.4 mg/kg, three mallards died but not until the eighth dose. One bird that was debilitated for 3 days after the last dose had a pellet lodged in its gizzard, indicating that birds can hold pelletized WP for several days after ingestion. Of 10 mallards dosed at 3.4 mg/kg, 6 died during the study, the first after two doses. One survivor also had a smoking gizzard four days past the last exposure. Pathological damage was extensive in both groups of birds and included fatty liver degeneration, liver necrosis, kidney damage, decreased hematocrit and hemoglobin, decreased number of lymphocytes, and elevated heterophil counts. Our lowest dose was above the lowest observable effects level (LOEL) for repeated doses because 1.3 mg/kg can alter reproduction in females, but we estimate that the LOEL for single doses is approximately 1–2 mg/kg.

*Secondary toxicity of WP in American kestrels fed treated chicks*

To assess the potential for secondary toxicity, we dosed 10-day-old poultry chicks with three pellets of white phosphorus over a 24-hr period. These chicks were then euthanized and frozen. Later, we divided the chicks into two groups. One group (NoGut) had the upper digestive system (crop, proventriculus, and gizzard) removed; this dissection was to remove any intact pellet from the digestive system to determine if predators can be intoxicated by tissue levels alone. The other group (Pell) was kept intact and a 1.1-mg pellet of WP was surgically placed into their crop; this simulated a prey item with undigested WP in its gizzard or crop. A third group of chicks was undosed controls. These chicks were subsequently fed to American kestrels for 7 days, when 50% of the kestrels on the Pell diet had died. Tissue levels in chicks were similar to those found in waterfowl and the 1.1-mg implanted pellet represented a dose of 6.8–10.8 mg/kg body weight in the kestrels, similar to that potentially encountered by eagles feeding on gizzards of dead or dying waterfowl. Of 15 kestrels on the Pell diet, 8 died during the study, the first after only 2 days. Of 15 kestrels on NoGut diet, 3 also died but only on the fourth (1) and tenth (2) days of treatment. Pathological effects were observed among survivors in both groups compared to controls. Significant differences occurred in hematocrit, weight loss, liver/body ratio, and hemoglobin. WP was found in the tissues of kestrels from both the NoGut and Pell treatments. The study showed that predators are at risk of intoxication when they eat either the carcass or gizzards of moribund and dead waterfowl.

*Development of semi-permeable membrane device (SPMD) to evaluate white phosphorus presence in water and sediment*

Preliminary steps have been completed in determining if SPMDs can be used to monitor water and sediments for the presence of WP. A problem occurs in that the vapor pressure difference between WP and the solvent isooctane is only $1.1 \times 10^3$, which is too low for reliable extraction. Therefore, n-pentane, which has a vapor pressure differential of $1.2 \times 10^4$, is being tested instead.

**Steele, B.B., and L.R. Reitsma** (1996) Waterfowl use and mortality at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 157–174.

The objectives for 1995 were to monitor waterfowl mortality at ERF, measure mortality in an uncontaminated reference area, measure mortality in non-contaminated areas of ERF, and evaluate mortality in swans. Mortality at ERF was compared to previous years to monitor decreasing exposure of ducks to white phosphorus from either remediation efforts or natural processes. We measured mortality in uncontaminated reference areas to develop a background level of mortality so that mortality rate at ERF can be used as a measurement endpoint. Mortality was measured by the same methods used since 1992. Counts of carcasses on permanent transects were compared to the number of ducks exposed, calculated from censuses made each morning. Mortality on reference areas was measured by the same method.

The mortality rate at ERF during fall 1995 was lower than in fall 1994. This decline continues a trend that has been seen since 1992, when the mortality rate was approximately ten times higher than in 1995. The fact that the mortality rate decreased in 1995 despite an increase in exposure rate shows that this decline does not result from hazing or other activity on the Flats. Rather, ducks are less exposed to white phosphorus because of natural attenuation, sedimentation on top of contaminated pond bottoms, or high water causing ducks to feed in non-contaminated areas.

The mortality rate in spring was very low but could not be compared statistically to previous years because of a low exposure rate and because no carcasses were found on transects. Only one carcass was found on transects in reference areas in Goose Bay and Susitna Flats. Thus, background mortality may be as much as one tenth that currently occurring at ERF, but more data are needed to accurately measure background mortality. We found only one carcass on transects in uncontaminated areas of ERF (Areas B and D). These areas still do not represent a hazard to ducks. Five swan carcasses were found, mostly before swans had been observed in contaminated areas. These deaths raise the possibility that swans ingest white phosphorus in areas thought to be safe for ducks: Area D, Area B, or the pond in Area C/D. Swans feed in deeper water than ducks and may be exposed in different areas than ducks are.

The fact that the mortality rate continues to decline before full-scale remediation has begun suggests that the no-action alternative may be sufficient to remediate at least some areas of ERF.

**Steele, B.B., L.R. Reitsma, and S.L. Burson** (1997) Waterfowl mortality on Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 19–20.

New safety regulations precluded walking on permanent mortality transects in 1996. Counts of ducks from Cole Point indicated duck populations similar to other years. Duck use of Bread Truck Pond was substantially reduced but not eliminated by the excavation of a drainage ditch. Canoe surveys of Racine Island and Area A indicated that mortality is still occurring in these areas.

**Walsh, M.E.** (1994) Appendix A: Method documentation in USATHAMA format: Analytical method for white phosphorus in soil or sediment (KN01). Revised in April 1992. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 341–369.

*Analyte*

This method is suitable for determining white phosphorus ($P_4$).

*Matrix*

This method is suitable for determining white phosphorus ($P_4$) in wet soil or sediment.

*General method*

A 40-g subsample of wet soil or sediment is placed into a 120-mL vial containing 10.0 mL of isooctane and 10.0 mL of degassed water. The sample is vortex-mixed for 1 minute, then placed horizontally on a platform shaker for 18 hours or overnight. The sample is then allowed to stand vertically for 15 minutes to allow phase separation. A 1.0-mL aliquot of the isooctane layer is analyzed on a gas chromatograph equipped with a nitrogen-phosphorus detector.

**Walsh, M.E.** (1994) Field study of air-drying contaminated sediment. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 312–322.

The effect of air-drying of contaminated sediments under field conditions on WP concentrations was tested. Highly contaminated sediment was excavated and placed in 1-m-diameter plots on land at the edge of ERF. After 56 days of air-drying, WP concentrations were reduced to undetectable levels. Visual examination of some of the dried sediments revealed voids or cavities left following sublimation of WP particles. Drying is a viable and important method for remediation of WP-contaminated sediments but may require removal of contaminated sediments from the bottoms of permanently flooded ponds. Artificial drainage of these ponds may also produced sufficient drying of contaminated sediments to reduce or eliminate WP, but the feasibility of this method is not known.

**Walsh, M.E.** (1994) Review of chemical and physical properties of WP. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 111–132.

Literature describing the physical and chemical properties of white phosphorus was reviewed for factors that influence the persistence of white phosphorus in the environment. Physical properties such as aqueous solubility, dissolution rate, octanol/water partition coefficient, and vapor pressure indicate that solid white phosphorus will persist indefinitely in saturated sediment. In unsaturated sediment, solid white phosphorus has the potential to sublime (vaporize). The rate of sublimation increases with temperature. Once in the vapor phase, WP may react with oxygen or diffuse out of the sediment. Any factor that slows sublimation will contribute to persistence of WP.

**Walsh, M.E.** (1994) Water sampling. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 185–190.

During 1993, water samples were also obtained and analyzed for WP. CRREL collected 12 water samples from five sites in Area C where WP had previously been detected in the sediment. White phosphorus was detectable in the water column overlying contaminated sediment. In general the WP concentration in water was over 1000 times less than the concentration in the sediment. Disturbance of the underlying contaminated sediment increased the concentration of WP in the water column.

AEHA collected water samples from 22 sites in ponds, distributaries, and the Eagle River. White phosphorus was detected in the water column at six sites where the sediments were also highly contaminated. The WP concentration ranged from 0.013 to 0.069 μg/L in unfiltered samples water. White phosphorus was not detectable in water overlying uncontaminated sediments.

**Walsh, M.E.** (1994) White phosphorus in plants at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army Garrison, Alaska, Directorate of Public Works, FY93 Final Report, p. 263–265.

Plant samples were collected from sites in Area C where WP was previously detected in the sediment. Samples of *Zannichellia palustris, Carex Lyngbyaei, Scripus paludosus, Hippurus tetraphylla, Potamogeton pectinatus,* and *Triglochin maritima* were minced in isooctane and the extract analyzed by gas chromatography. WP was detectable in the roots of *Carex Lyngbyaei* (2.27 μg/g) and *Zannichellia palustris* (0.16 μg/g), both of which were growing at sites with WP sediment concentrations exceeding 2000 μg/g. While it is unlikely that plant materials (seeds and leaves) represent a major food chain pathway of exposure to WP for herbivores, the sorption of WP to organic plant detritus (dead plant pieces in the sediments) may provide a pathway to invertebrate detritivores.

**Walsh, M.E., and C.M. Collins** (1995) Investigations of natural size reduction of white phosphorus particles in Eagle River Flats sediment. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 471–528.

Remediation of sediments at Eagle River Flats, a salt marsh contaminated with solid particles of white phosphorus (WP), may require severe alterations of the wetland by dredging, draining, or covering. However, some sediments may undergo WP decontamination naturally in areas that are seasonally subaerially exposed and where sufficient drying of the sediment occurs. The persistence and attenuation of millimeter-size white phosphorus particles was studied by laboratory and field experiments.

In laboratory experiments where WP particles were incubated under constant moisture contents (degree of saturation = 0.45, 0.64, 0.82, 1, or >1) and temperatures (4, 15, or 20°C), WP particles were persistent at moisture contents at or above saturation. Laboratory-constructed WP particles incubated well below saturation (saturation level = 0.45 or 0.64) were lost rapidly (24 hours) at 20°C, within 30 days at 15°C, and persisted over the time interval tested (approximately 60 days) at 4°C. For samples incubated slightly below saturation (saturation level = 0.82), results were variable, with significant loss in some samples and no change in other samples.

In field experiments on ERF, WP particles were incubated at 5 cm depth in salt marsh sediments at 10 monitoring sites ranging from permanently flooded ponds to intermittently flooded ponds to unflooded mudflat and levee sites. WP particles were persistent in the permanently flooded area, but there was loss of WP in areas with unsaturated exposed sediments. Unsaturated conditions were detected down to 30 cm at monitoring sites on the river levee and mudflat and two intermittent pond sites, indicating that loss of WP is possible at depth. However, at depth, loss is likely to be slower owing to consolidation, lower temperatures, and longer periods of saturation.

Resampling of an intermittent pond and WP-contaminated sites, identified and sampled in previous years, also showed loss of WP after the area was subaerially exposed in 1994.

Based on the above results, initial remediation efforts involving active manipulation of the site should be restricted to contaminated permanently ponded areas. At intermittent pond sites where natural attenuation can occur, WP levels should be monitored for continued loss of WP.

**Walsh, M.E., C.M. Collins, and R.N. Bailey** (1996) Enhancement of intrinsic remediation of WP particles by sediment warming in intermittent ponded areas of Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and

D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 249–266.

This task was to study the enhancement of reduction of WP particles in intermittent ponded areas by sediment warming. The most important condition for loss of WP particles from ERF sediments is desaturation of the sediments, which occurs in summers with long periods between flooding tides. A secondary factor is sediment temperature. Since the vapor pressure of WP increases exponentially with temperature and oxidation is more likely at higher temperatures, loss of WP particles can be significantly accelerated by warming unsaturated sediments.

A field study was performed to test the effectiveness of passive solar warming techniques on increasing sediment temperature and promoting the loss of planted WP particles. One technique tested was the application of black sand to change the surface albedo. Also tested were two types of synthetic row covers (a spun-bonded polyester and a porous polypropylene) commonly used in agriculture. The row covers transmit short-wave (300–2500 nm) solar radiation and trap long-wave radiation (4000 nm) from the sediment surface, producing a greenhouse effect. Sediment temperatures were monitored at a depth of 5 cm, and all three treatments slightly increased the sediment temperatures relative to the controls. Because of monthly flooding tides during the summer of 1995 and frequent rainfall during July, August, and September, sediments were saturated except for a few days prior to the June flooding tides. None of the treatments appeared to significantly inhibit evaporation during this brief period of favorable drying conditions. The amount of time when sediments were unsaturated was so short that most WP particles remained essentially unchanged, except for a few particles under one of the row covers and one particle in the control plot. These results show that row covers are a tool that may be used to raise sediment temperatures, but attention must be focused first on enhancing desaturation of the sediments using methods such as temporary pond drainage.

A laboratory experiment was also performed using a more aggressive method to heat sediments with planted WP particles. The purpose of the experiment was to test the hypothesis that heating the sediments would increase the vapor pressure of the WP sufficiently to initiate oxidation, which in turn would generate heat to sustain continued sublimation and oxidation after the outside heat source was removed. To test this hypothesis, unsaturated sediments were equilibrated at 13°C (typical average temperature for ERF sediments during the first part of June), and then a hot air gun was used to heat the sediments briefly to 40°C. Then, the sediments were cooled to 13°C and WP particles were recovered. This treatment failed to rapidly remove WP from the sediments. The average WP mass remaining in the heated sediments was not significantly different from the control, indicating that a longer period of heating would be necessary to accelerate WP loss. However, the energy requirements for prolonged heating in situ would be prohibitive.

Given that intrinsic remediation is occurring in some parts of ERF in areas that naturally desaturate, ways to enhance natural drying should be employed where possible before active methods of raising sediment temperatures. A third task was to study the reduction in size of WP particles following pond drainage. This was conducted in conjunction with the pond drainage treatability study by C.M. Collins. Along a transect through the intermittently and permanently flooded areas of the Bread Truck Pond, WP particles were planted in May at a depth of 5 cm, and the sediment moisture and temperature were monitored at 5- and 10-cm depths at sites. Because of procurement delays, the pond was not drained and sediments remained saturated throughout the summer.

A fourth task was to study the reduction in size of WP particles in dredge spoils. This was conducted in conjunction with the dredging treatability study by M.R. Walsh. To determine if the moisture levels and temperatures of the spoils reach those conducive for decontamination, monitoring sites were set up at four locations within the basin, and when dredging was completed for the season in September, WP particles of known mass were placed at known locations. The residue from these particles will be recovered next spring.

**Walsh, M.E., C.M. Collins, and R.N. Bailey** (1996) Intrinsic remediation of WP particles in intermittent ponded areas of ERF. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 231–248.

Natural attenuation of WP particles appears to be occurring at a highly contaminated site (Site 883) in the intermittent pond of Area C. When 41 samples were taken at this site in the fall of 1995 at the same locations as 41 samples in the fall of 1992, the number of samples with WP concentrations greater than 10 µg/g declined from four to zero, and the number of samples below 0.001 µg/g has increased from 15 to 28. In addition the number of WP particles at this site has decreased; in 1992, when 270 mL of sediment from this site was sieved, over 100 WP particles were isolated. In 1995, 1000 mL of sediment was sieved using the same procedure, and only one WP particle was found. Sediments at this site were desaturated during the summers of 1993 and 1994 when weather conditions and the length of time between flooding tides were favorable for pond shrinkage. During 1995, flooding tides occurred monthly, and sediments at this site were continually under water.

Samples were also obtained from the crater produced from the detonation of a WP UXO in 1992. The crater is also in the intermittent pond of Area C. The rim of the crater, which had a WP concentration of nearly 1000 µg/g when sampled in 1992, had concentrations of 0.0051 and 0.0006 µg/g when sampled in June and September 1995. The bottom of the crater, which is 32 cm below the rim, still has high concentrations of WP. The bottom of the crater was exposed in 1993 and 1994, but for much shorter lengths of time than the rim. WP particles were isolated by sieving 1000 mL of sediment from the crater bottom, and over 100 particles were found, most of which were less than 1 mm in length. WP particles were also isolated from a permanently saturated site on Racine Island. While most of the WP particles isolated were also less than 1 mm in length, several large particles (greater than 2 mm) were also found, with the largest particle measuring 6.6 mm in length. Such large particles were absent from sites in the intermittent ponded areas. We hypothesize that when sediments are exposed and desaturate, the smallest WP particles are the least persistent and disappear relatively quickly since small particles have large surface-to-volume ratios and sublimation occurs from the particle surface. Larger particles are much more persistent but shrink during periods of desaturation.

**Walsh, M.E., C.M. Collins, and R.N. Bailey** (1997) Demonstration of sample compositing methods to detect white phosphorus particles. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 35–50.

White phosphorus is a difficult contaminant to characterize in the environment. Spatial heterogeneity of concentration estimates is extreme, varying over many orders of magnitude for closely spaced discrete samples. Therefore, any attempt to determine remediation success at ERF based on concentrations found in sediment samples would be costly owing to the enormous number of samples required to make an informed decision. Because the goal of remediation at Eagle River Flats is to reduce waterfowl mortality, we developed a composite sampling method designed specifically to determine the presence of white phosphorus particles (the form responsible for acute poisoning of waterfowl at ERF), and we demonstrated the feasibility of this approach in a contaminated pond in Area C.

To form each composite, many small samples were pooled and passed through a 0.59-mm mesh to remove the fine-grained material. The material left on the mesh was examined for white phosphorus particles. The samples were collected on square and triangular grids, and the distance between samples was based on the assumption that most of the available white phosphorus is located in hot spots with radii of approximately 1 m. Unless the number of hot spots is large, the distance between samples must be on the order of 2 m to maintain a low risk of not hitting a single hot spot. The area we sampled was highly contaminated, and white phosphorus particles are still abundant within the top 9 cm of sediment.

For this study we also collected and analyzed individual discrete samples. The concentrations found in these samples showed that sites with high white phosphorus concentration and containing solid pieces of white phosphorus are indeed located within small areas (hot spots) punctuating a much larger area containing low concentrations of white phosphorus. This spatial heterogeneity necessitates closely spaced sampling, which in turn requires compositing to reduce analytical costs.

We believe composite sampling will provide cost-effective data upon which decisions may be made as to whether an area remains contaminated with white phosphorus particles.

**Walsh, M.E., C.M. Collins, and R.N. Bailey**



to contents to index

(1998) Treatment verification: Monitoring the remediation of white-phosphorus-contaminated sediments of drained ponds. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 41–62.

We monitored the effectiveness of pond draining on the remediation of white-phosphorus-contaminated sediments. Transects were established in Area C (ponds 164 and 183), which was drained by pumping, and in the Bread Truck Pond (ponds 99 and 109), which was drained by breaching. The 200-m-long transects extended from what was intermittent pond on the west side to what was permanent pond on the east side. At 100-m intervals, dataloggers recorded the output of sediment moisture and temperature sensors, and the attenuation of planted white phosphorus particles was measured. At 50-m intervals, composite samples were collected from gridded areas extending 20 m north and south of the west–east transects.

Pumping was very successful at drying the surface sediments of Area C. Breaching of the Bread Truck Pond has resulted in some drying of the surface sediment, but a topography characterized by swales and craters that do not drain and a lower tidal flooding threshold slow the potential attenuation rates.

Sublimation / oxidation conditions were favorable for removal of some white phosphorus from the surface sediments of Area C and the Bread Truck Pond. An approximately 50% decline in mass, from 5.56 to 2.8 $\pm$ 0.9 mg, was found for white phosphorus particles planted in the surface sediments of Area C and the Bread Truck Pond. Composite samples taken in June from Area C and the Bread Truck Pond showed that most of the contamination was located at the midpoint of transects running west to east from intermittent to permanently flooded ponds. Resampling in September showed significant declines (>80%) in white phosphorus concentrations in Area C and the south side of Bread Truck Pond. Because the mass of white phosphorus found in the composite samples is the sum of a range of particle sizes, from colloidal to macroscopic, and because small particles take less time to attenuate, we see greater loss for those composite samples that had particles smaller then the manufactured particles. The composite sample taken in September from the north side of the Bread Truck Pond, where drying conditions were variable and white phosphorus particles were large, did not show a detectable change in concentration from the June sample.

Additional composite samples were taken from Pond 40 of Area C / D. No white phosphorus was detected by composite sampling, indicating that this pond is not a serious threat to waterfowl.

Finally, monitoring of the dredge spoils continued. The dredge spoils were air-dried in the retention basin during 1997, and no white phosphorus residue was found from particles planted in 1995.

**Walsh, M.R.** (1996) Development of a remotely controlled drilling and sampling system for remediation program at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 345–364.

The goal of this project was to develop, build, test, and deploy a remotely operated drilling / coring platform for use in the Flats to assist in the study of remediation efficiencies for these projects. A market survey, including visits to manufacturers, was conducted and the capabilities of various equipment configurations discussed. Additional discussions were held with drilling experts at CRREL in New Hampshire and Alaska. From these discussions, a set of specifications was developed and bid requests sent out through the Ft. Richardson contracting office for a small, lightweight, mobile drill.

Concurrent with this contracting effort, the U.S. Army Tank Automotive Research, Development, and Engineering Command in Warren, Michigan, was tasked to develop, build, and test a remote-control system for a vehicle similar to the carriers used with the drilling systems reviewed. A 6 × 6 vehicle was available for this purpose and sent to TARDEC as a test bed. Specifications for a remote camera system were also developed and a system ordered.

Contracting delays resulted in the awarding of the contract on 22 July, with an early September delivery date. This precluded any meaningful work at the Flats for the 1995 season, but through a superb effort by TARDEC, a working, tested system was delivered to the Flats on the 28 September. The drill unit is now in storage at Ft. Richardson, ready for a spring deployment for the 1996 field season.

The drilling of the EOD Pad wells also faced daunting contracting delays, but they were drilled and installed the last week in September. Seven wells, each 6 m deep by 10 cm in diameter, were placed at the corners and down the middle of the EOD Pad. As work had ceased before completion of the wells, no attempt was made to instrument the wells with depth sensors. A groundwater-sampling plan will need to be developed prior to sampling for chemical analysis.

The final task was to develop a remote-controlled coring machine for use in the Flats. This was to be a follow-on to the drill machine. Because of the delays in the drill project, development of the coring unit is delayed until FY 96. Work has been initiated in conjunction with TARDEC on retrofitting an M501 Hawk missile loader for this task using carry-over funds.

In summary, it was a frustrating field season, with two of the three tasks coming very close to completion, but being foiled by contract delays. The only positive aspect to this situation is that a wet field season and contract delays in other programs resulted in the equipment not being needed as much this season as it will be next season. With the wells in place, a full season's data can be collected during next year's dredge deployment.

**Walsh, M.R.** (1996) Dredging as a remediation strategy for white phosphorus contaminated sediments at Eagle River Flats. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY95 Final Report, p. 311–344.

This project covers the second deployment of the dredging system and the various factors involved in dredging and remediation of the spoils. This season's work can be divided into three categories: continued investigation of the hydrological properties of the Retention Basin, dredge operations, and initiation of the attenuation study in the Basin.

The hydrological studies of the Basin liner were conducted in mid-June. They consisted of constant-head percolation tests, in-situ density tests, and moisture content tests. The percolation tests were run over a period of up to 9 days. While most tests indicated a percolation rate below the acceptable level of $10^{-6}$ cm/s, one test exceeded that level ($<5 \times 10^{-6}$ cm/s). However, the overall performance of the liner was sufficient for us to judge it acceptable for use again this year. In addition, moisture content and densities were tested near the percolation tests to complete the characterization of the Retention Basin liner. Moisture contents ranged from around 30% to around 70%. Densities generally ran around 0.9 g/cm$^3$ (55 lb/ft$^3$).

Some erosion had occurred around the concrete splash pad at the spoils line outlet, so a wooden weir was constructed along one side and flow channels around the remaining sides were blocked with stones. Finally, the geotextile silt fence at the drop inlet structure was subjectively checked with a knife to assure integrity. It was left in place and covered with a tarp to reduce exposure to UV rays. Later problems with low supernatant salinity levels forced us to forego the use of the silt fence because of clogging.

Continued problems with the dredge equipment and the unique environment at the Flats precluded its full operation until September. At that time, the slurry pump had been reconfigured, the dredge sensors reprogrammed, the electrical work finished, spoils line repaired, the boom box removed, a new grate system installed on the dredgehead, and the lateral winch deadmen anchored. During dredge operations, 160 spoils-line sediment samples and 23 supernatant (water) samples were obtained and analyzed, with a total of 26 sediment sample WP hits and one water hit. The average concentrations were 6.16 and 4 µg/kg for the sediment and water sample hits, respectively. Approximately 1650 m$^3$ of material was dredged from Clunie Inlet and Area C between and adjacent to Clunie and Canoe Points. Using the results of the analysis of the spoils, about 1420 lethal doses of WP were removed during dredging (based on a 37% mallard, 37% pintail, 26% teal mix). The fine particle size of the suspended solids in the supernatant diminishes the lethality of any WP returned to the Flats.

The attenuation study was initiated and some data obtained from the instrumentation installed in the Retention Basin. Six particles were planted in partially dewatered spoils in four locations, two adjacent to instrumentation stations, on 28 September. The dataloggers were allowed to operate until 7 December. At that time, the temperature was well below zero and the spoils had frozen solid. Only partial drying of the sediments occurred before freezeup, so definitive data will not be collected and analyzed until next spring.

Because of equipment problems, it was not possible to dredge the entire 0.85-ha area that had been planned. However, by the end of the season, the dredge system was operating reliably and effectively. The ability of the dredge to remove contaminated material from the Flats has been demonstrated, although the cost will be high. The performance of the Basin as a remediation structure should be determinable by next July.

**Walsh, M.R., E.J. Chamberlain, and D.E. Garfield** (1995) Dredging as a remediation strategy for white phosphorus contaminated sediments at Eagle River Flats, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.H. Racine and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY94 Final Report, p. 563–632.

Investigations into the fate and persistence of white phosphorus (WP) at Eagle River Flats, Alaska, indicate that, although natural attenuation is occurring in areas where intermittent drying takes place, permanently flooded areas are retaining lethal amounts of the chemical. Several remediation strategies for these persistent areas were initiated during the 1994 field season, covering a range of methodologies, including covering contaminated areas, siphoning small permanently ponded areas, and dredging larger permanent ponds. This project covers the preparations and initiation of the dredging remediation operation.

Initial investigations centered on the feasibility of dredging in an active impact area. Discussions with several small dredge manufacturers indicated that a remotely controlled dredge configured to minimize damage in the case of the detonation of an unexploded round would be feasible. A list of technical specifications was developed and sent to the USARAlaska Contracting Office to be included in the RFQ for a dredge system lease. CRREL engineers then worked with the Contracting Officer in bid evaluation. The contract was awarded to ChemTrack of Anchorage, Alaska.

Design of the dredge spoils retention basin was a major task in the overall project. The chosen site, the EOD Pad, is a Solid Waste Management Unit within a RCRA site. As such, much site characterization work was required by the Restoration Program Managers before approval was given for site use. Extensive testing and design work, done in association with the U.S. Army Engineer District, Alaska, was required. Site characterization and extensive testing was conducted by CRREL engineers. The design work was carried out by District engineers using data gathered from the testing. A 0.8-ha retention basin with 2-m berms was designed. The structure is lined with a peaty-silt soil, which reduces conductivity to $\approx 1 \times 10^{-6}$ cm / s below the $1 \times 10^{-5}$-cm / s threshold. A drop inlet structure is located at one corner of the basin for decanting supernatant through a weir and silt fence. Two concrete pads are constructed within the basin for spoils line outfall to prevent erosion of the basin liner. The basin will be reusable with the removal of the treated spoils. Instrumentation was installed in the basin to monitor temperatures, water level, and soil moisture. A tap was installed in the spoils line adjacent to the basin for spoils sampling.

Owing to procurement delays, equipment modifications dictated by the Safety Plan, and the incomplete state of the equipment on delivery, actual dredging did not commence until mid-October. Because of problems with some of the equipment modifications and the onset of winter, only about 2 hours of actual dredging over a 2-day span was conducted during October 1994. Two samples were taken from the spoils line, one of which was highly contaminated with WP (2.7 µg / g). Owing to the short amount of operational time in the 1994 field season, a judgment as to the feasibility of dredging cannot be made. However, the ability of the dredging system to remove WP-contaminated sediments has been demonstrated.

**Walsh, M.R., and C.M. Collins** (1997) Monitoring of contract dredge operations at Eagle River Flats, Alaska. In *Interagency expanded site investigation: Evaluation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY96 Final Report, p. 73–100.

Investigations into the fate and persistence of white phosphorus (WP) at Eagle River Flats (ERF), Alaska, indicate that WP is persistent in the permanently ponded areas of ERF. Several remediation strategies for these WP-contaminated areas were initiated or implemented in the 1994–1996 field seasons, encompassing a range of methodologies, including covering contaminated areas, designing equipment for the draining of large contiguous ponds, enhancing natural attenuation in intermittently flooded areas, pond draining through explosive trenching, and dredging. The objective of this project is to monitor the commercial implementation of a small, remote-controlled dredge designed to remove sediments from contaminated ponded areas and to continue an efficacy study of the treatment of the spoils in an open retention basin. The treatment method will be the natural attenuation of the white phosphorus, once conditions of the sediments in the basin are conducive to sublimation.

Dredging was chosen as a method of remediation because of the positive removal of the contaminated material and the ability to treat the material in a controlled environment. By using a small, remote-controlled dredge, limited areas could be dredged, and the contaminated material (spoils) can be quickly and efficiently transported to a retention basin for treatment. Environmental impact to the salt marsh system, although not negligible, can be minimized through a careful dredging strategy. Because of the presence of unexploded ordnance, an unmanned system was required.

This is the third year of the dredging project at Eagle River Flats. The first year primarily involved processing a contract for the dredge equipment; designing, constructing, and testing a spoils retention basin; integrating specialized equipment to the dredge; getting the leased equipment operational; and test dredging a small area at the Flats. During 1995 three tasks were undertaken: continued investigation of the hydrological properties of the retention basin; dredge operations; and initiation of the attenuation study in the Basin. This year, 1996, the operation of the equipment was turned over to a local contractor. An area was designated for dredging, and technical assistance was provided for the initial setup and operation of the equipment.

Although all sampling and testing was originally cut from the project proposal, limited sampling and testing were conducted in the basin and on the spoils entering the basin. Datalogger stations were reinstalled in the basin to monitor such parameters as air and soil temperature, soil moisture, and water level. Prior to the start of dredging, two percolation tests were performed in the basin. Both tests indicated a percolation rate above the acceptable level of 10–6 cm/s. The higher percolation rates are probably attributable to the reduction in liner density caused by the severe freeze–thaw cycling that occurred over the previous winter, when lack of snow exposed the liner to solar and temperature variations. The lack of funds for improving the liner, as well as the proximity of the test results to acceptable levels, resulted in the use of the basin in the condition found.

In December 1995, a list of possible improvements to the equipment was given to the contractor. A few of these changes were implemented prior to dredging and more during dredging as the contractor saw the need for them after familiarization with the equipment and operation. The primary change to the equipment was the placement of the auger drive behind the augerhead, rather than on its side. This change was not implemented as recommended, however, and the 3-in. protrusion on the side of the augerhead enclosing the drive continues to be problematic. Stress on the augerhead cutter resulted in the breakage of one auger assembly, which was quickly replaced by the contractor using one of the spare units on hand. The contractor made some improvements to the system, and the system continues to work fairly well. A patent application has been submitted for this device.

Anchoring points continue to be problematic. The contractor was convinced shortly after startup that the lateral winch system was not feasible in the Flats environment, and a manually adjustable system was devised using telephone pole anchors, similar to the anchoring system used last season. This eliminated the need for helicopter support, thereby saving a substantial sum of money and logistical effort. Further work on this system is required. Improvements to the spoils transfer line eliminated any blowouts like those experienced last year. The contractor is currently looking into a radio-control package to improve reliability of the dredge control system.

In September, funding was received to enable a trip to collect and analyze bottom samples and to survey the area dredged. Survey data indicate that the dredged depth is around 51 cm, significantly less than the 90 cm specified. The area dredged is approximately 0.29 ha. Results of the spoils line sample analyses indicate that contaminated material continues to be transferred from the Flats to the retention basin. Of 12 spoils samples analyzed, three were contaminated with white phosphorous. One of five water samples taken from the outflow line was slightly contaminated (<1 µg/L). The small number of samples taken limits the conclusions that can be drawn from the data, although results are similar to the larger sampling program conducted in 1995.

**Walsh, M.R., C.M. Collins, and D.J. Lambert** (1998) Implementation of a remote pumping system for white phosphorus remediation in Pond 183. In *Interagency expanded site investigation: Evalu-*

*ation of white phosphorus contamination and potential treatability at Eagle River Flats, Alaska* (C.M. Collins and D. Cate, Ed.). CRREL Contract Report to U.S. Army, Alaska, Directorate of Public Works, FY97 Final Report, p. 81–100.

In 1997, funds became available for the feasibility study of pond pumping for remediation. A pump system, consisting of an 80-kW generator set, a separate 7.56-$m^3$/min (2000 gpm) pump, and 335 m of 20-cm-diameter discharge line, was available for this study. Originally planned for use in Pond 109, the decision was made to try to treat Pond 183 (C Pond) with this system. Pond 183 is not as isolated as Pond 109 and is much larger. It is also interconnected with a large number of adjacent ponds, including Pond 146, where dredging had been conducted, and Pond 155 (Lawson's Pond), another highly contaminated pond. Recharge from Clunie Creek and seeps along the shore of Ponds 146 and 40 were also thought to be problematic.

The overall performance of the pumping system was much better than expected. The system easily addressed the target area and influenced a wide area surrounding it as well. Improvements to the system increased its reliability and decreased the amount of human intervention required to keep the system operational. A second pump system, incorporating most of the features developed during deployment and operation of the first system, was ordered, received, and operational within 2 days. It has been run-in and will be ready for deployment when needed, after some minor modifications.

The results from the sampling study indicate the remediation may be possible over the course of 3 good drying years (>60 core days without heavy rainfall). Based on composite sampling results, more than 84% of the white phosphorus was remediated over the summer, and approximately 55% of planted particles' mass (5.56 mg original mass) attenuated over the same time span. For areas that may dry more slowly or flood more often, the term may be closer to the 5 years predicted by CH2M HILL. Sumps are ready for pump deployment in Ponds 155 and 290, and a route has been marked for clearance and access to Pond 146 next year. With pumps in Ponds 146, 155, and 183, drawdown should be much more rapid than this season's, perhaps less than 24 hours.

The pumped drainage of permanently ponded areas and their associated intermittent ponds is an almost ideal solution to the problem of white phosphorus contamination in Eagle River Flats. The relatively low costs and mild environmental impact of this remediation method make it a very viable option where it can be applied. It may even negate the need for bentonite coverage of most targeted areas. It should be considered in as many contaminated areas as feasible.

---

## JOURNAL ARTICLES

**Clark, L., J. Cummings, S. Bird, and E. Aronov** (1993) Acute toxicity of the bird repellent, methyl anthranilate, to fry of *Salmo salar, Oncorhynus mykiss, Ictalurus punctatus* and *Lepomis macrochirus*. *Pesticide Science*, **39**: 313–317.

Several laboratory and field studies have shown methyl anthranilate to be an effective, non-toxic, and non-lethal bird repellent, with application potential for protecting crops, seeds, turf, and fish stocks from bird damage. Furthermore, methyl anthranilate can be added to liquids for the purposes of protecting migratory birds, e.g., addition to waste water associated with mining and to standing water pools at airports. Mammalian toxicity data are favorable. Methyl anthranilate is used as a fragrance and food flavoring and is GRAS listed by the U.S. Food and Drug Administration. Despite the favorable outlook for methyl anthranilate's use as a safe repellent, no data exist on its environmental fate and effects. We have tested the acute toxicity of methyl anthranilate in a static system against the fry of four species of fish. The $LC_{50}$ at 24 hours for Atlantic salmon (*Salmo salar* L.) was 32.3 mg $L^{-1}$, with the no observable effect limit at 6 mg $L^{-1}$. The $LC_{50}$ at 24 hours for rainbow trout (*Oncorhynus mykiss* Richardson) was 23.5 mg $L^{-1}$, with the no observable effect limit at 5 mg $L^{-1}$. The $LC_{50}$ at 24 hours for channel catfish (*Ictalurus punctatus* Raf.) was estimated to be 20.1 mg $L^{-1}$, with the no observable effect limit at 7 mg $L^{-1}$. The $LC_{50}$ at 24 hours for bluegill sunfish (*Lepomis macrochirus* Raf.) was estimated to be 19.8 mg $L^{-1}$, with the no observable effect limit at 7 mg $L^{-1}$.

**Henry, K.S., M.R. Walsh, and S.H. Morin** (1999) Selection of silt fence filter to retain suspended toxic particles. *Geotextiles and Geomembranes*, **17**: 371–387.

A silt fence filter was required to retain potentially toxic particles of 0.1-mm diameter and larger that could become suspended in water decanted from contaminated dredge spoils. An experimental study was perfomed to select it. The experiments consisted of two parts, Part 1 tests were conducted according to an accepted engineering standard to compare four candidate geotextiles. Part 2 tests simulated expected field conditions, and were conducted to determine whether one geotextile selected from the Part 1 tests was likely to perform well. The geotextile seleted for Part 2 tests retained particles of 0.1 mm and larger, and was installed as a silt fence filter in the field. The silt fence filter was removed shortly after dredging began because it clogged, primarily due to unexpeted, high amounts of suspended sediment in the supernatant. The design of the support structure for the silt fence did not permit maintenance of the filter, which may have prevented its failure. The failure may also have been prevented if salt or other materials used to promote flocculation of the dredged spoils were readily available and used on the spoils. The selection procedure described may be helpful beause the conditions tested for in the laboratory are likely to occur or could be induced.

**Nam, S.I., D.L. MacMillan, and B.D. Roebuck** (1996) The translocation of white phosphorus from hen (*Gallus domesticus*) to eggs. *Environmental Toxicology and Chemistry*, **15**(9): 1564–1569.

Thousands of waterfowl deaths occurring at Eagle River Flats (ERF), Anchorage, Alaska, U.S.A., have been attributed to the ingestion of white phosphorus ($P_4$) particles. White phosphorus has been found in the egg of one herring gull (*Larus argentatus*) and in the yolks of some shorebirds at ERF. The presence of $P_4$ in eggs suggests potential toxic consequences for avian reproduction. This study was undertaken to determine the magnitude and potential importance of $P_4$ translocation from the hen to the egg. Egg-laying hens (*Gallus domesticus*) were gavaged with a single dose of 1, 3, or 5 mg $P_4$/kg body weight or dosed with 1 mg $P_4$/kg body weight for 5 consecutive days. Eggs of dosed hens were collected daily. White phosphorus was extracted from the yolk and the white, individually, with isooctane and analyzed by gas chromatography. White phosphorus had no significant effect on chicken weight, egg weight, or shell thickness. However, laying frequency was significantly reduced ($p < 0.05$) in chickens receiving 1 mg $P_4$/kg body weight for 5 days. For all treatments, $P_4$ was detected in the yolk and not in the white. It was first detected in the yolk approximately 1 to 2 days after $P_4$ exposure and became nondetectable 6 to 10 days after $P_4$ exposure. The total $P_4$ recovered from eggs of chickens treated with $P_4$ was less than 0.01% of the administered dose.

**Nam, S.I., B.D. Roebuck, and M.E. Walsh** (1994) Uptake and loss of white phosphorus in American kestrels. *Environmental Toxicology and Chemistry*, **13**(4): 637–641.

American kestrels (*Falco sparverius*) exposed to a diet containing white phosphorus ($P_4$) had detectable quantities of $P_4$ only in their fatty tissues. As early as 24 hours after dosing, $P_4$ was found in the fat depots and skin but not in other tissues such as the brain, heart, intestine, liver, kidney, and muscle. After 7 days of continuous exposure to $P_4$-containing diet (6.4 µg $P_4$/g of diet), the skin but not the fat depots showed significant accumulation of $P_4$. When a $P_4$-containing diet (6.4 µg $P_4$/g of diet) was fed for 2 days followed by 3 days of feeding a diet containing less $P_4$ (0.7 µg $P_4$/g of diet), $P_4$ was not detectable in the tissues. Upon refeeding with the higher dietary concentration of $P_4$, $P_4$ was again detectable in skin and fat. This cyclic dosing regimen indicates that tissue levels are sensitive to dietary levels of $P_4$.

**Pochop, P.A., J.L. Cummings, C.A. Yoder, and W.A. Gossweiler** (in press) A physical barrier to reduce white phosphorus mortalities of foraging waterfowl. *Journal of Environmental Engineering*.

White phosphorus has been identified as the cause of mortality to certain species of waterfowl using Eagle River Flats, a tidal marsh in Alaska, used as an ordnance impact area by the U.S. Army. A blend of calcium bentonite/organo-clays, gravel, and binding polymers was tested for effectiveness as a barrier to reduce duck foraging and mortality. Following the application of the barrier to one of two contaminated ponds, we observed greater duck foraging and higher mortality in the untreated pond and no mortality in the treated pond after a year of tidal inundations and ice effects. Emergent vegetation recovered within a year of treatment. White phosphorus levels in the barrier were less than the method limit of detection, indicating no migration of white phosphorus into the material. Barrier thickness remained relatively stable over a period of 4 years, while vegetation was found to be important in stabilizing the barrier material.

**Racine, C.H., M.E. Walsh, B.D. Roebuck, C.M. Collins, D.J. Calkins, L.R. Reitsma, P.J. Buchli, and G. Goldfarb** (1992) White phosphorus poisoning of waterfowl in an Alaskan salt marsh. *Journal of Wildlife Diseases*, **28**(4): 669–673.

The cause of the yearly death of an estimated 1000 to 2000 migrating dabbling ducks (*Anas* sp.) and 10 to 50 swans (*Cygnus buccinator* and *C. columbianus*) has remained a mystery for the last 10 years in Eagle River Flats (ERF), a 1000-ha estuarine salt marsh near Anchorage, Alaska, used for artillery training by the U.S. Army. We have gathered evidence that the cause of this mortality is the highly toxic incendiary munition white phosphorus ($P_4$). The symptoms of poisoning we observed in wild ducks included lethargy, repeated drinking, and head shaking and rolling. Death was preceded by convulsions. Farm-reared mallards dosed with white phosphorus showed nearly identical behavioral symptoms to those of wild ducks that became sick in ERF. White phosphorus does not occur in nature but was found in both the sediments where dabbling ducks and swans feed and in the gizzards of all carcasses collected in ERF. We hypothesize that feeding waterfowl are ingesting small particles of the highly toxic, incendiary munition $P_4$ stored in the bottom anoxic sediments of shallow salt marsh ponds.

**Roebuck, B.D., S.I. Nam, D.L. MacMillan, K.J. Baumgartner, and M.E. Walsh** (1998) Toxicology of white phosphorus ($P_4$) to ducks and risk for their predators: Effects of particle size. *Environmental Toxicology and Chemistry*, **17**(3): 511–518.

Particles of white phosphorus ($P_4$) in pond sediments at Eagle River Flats, Alaska, U.S.A., a military artillery range are acutely toxic to dabbling ducks and swans. We determined if toxicity of $P_4$ to ducks varied by its form (i.e., dissolved or particulate) or particulate size. Residual $P_4$ in the digestive tract of ducks was measured to assess risks posed to predators and scavengers of ducks. Farm-reared mallards were treated with 12 mg $P_4$/kg body weight, either dissolved in oil, or as numerous small, or one to two large particles. At the first major convulsion, ducks were euthanized and the quantity and location of $P_4$ in the digestive tract were determined. These data were compared to data from dead ducks collected from the artillery range. Dissolved $P_4$, and small or large particles of it produced similar acute toxicity. Residual $P_4$ in digestive tracts was greatest in ducks treated with small particles and was as great as 3.5 mg $P_4$. Similar quantities of residual $P_4$ were found in dead ducks collected at Eagle River Flats. For dabbling ducks, $P_4$ particle size is not as important as the dose ingested. For predators, the $P_4$ contents of the entire digestive tract is important for assessment of the risk of poisoning.

**Roebuck, B.D., M.E. Walsh, C.H. Racine, L.R. Reitsma, B.B. Steele, and S.I. Nam** (1994) Predation of ducks poisoned by white phosphorus: Exposure and risk to predators. *Environmental Toxicology and Chemistry*, **13**(10): 1613–1618.

White phosphorus ($P_4$) has been identified as the cause of mortality for dabbling ducks and swans at an estuarine salt marsh in Alaska. Predation of ducks poisoned by $P_4$ was monitored to assess the extent and range of predator exposures to $P_4$. Avian tissues were analyzed for $P_4$ by gas chromatography. We observed that both sick and dead dabbling ducks were common prey of bald eagles (*Haliaeetus Ieucocephalus*), herring gulls (*Larus argentatus*), and common ravens (*Corvus corax*). Frank signs of $P_4$ intoxication attracted predators and rendered the ducks easy prey. White phosphorus was found in the tissue remains of ducks that had been preyed upon, thus providing positive evidence that predators were exposed to $P_4$. Although $P_4$ varied widely among individuals, $P_4$ was generally highest in the gizzard contents followed by fatty tissues such as fat depots and the skin. White phosphorus was identified in fatty tissues of one eagle and in one herring gull egg, thus providing direct evidence of absorption of $P_4$ by predators.

**Sparling, D.W., and N.E. Federfoff** (1997) Secondary poisoning of kestrels by white phosphorus. *Ecotoxicology*, **6**: 239–247.

Since 1982, extensive waterfowl mortality attributable to white phosphorus ($P_4$) has been observed at Eagle River Flats, a tidal marsh near Anchorage, Alaska. Ducks and swans that ingest $P_4$ pellets become lethargic and may display severe convulsions. Intoxicated waterfowl attract raptors and gulls that feed on dead or dying birds. To determine if avian predators can be affected by secondary poisoning, we fed American kestrels (*Falco sparverius*) 10-day old domestic chickens that had been dosed with white phosphorus. Of 15 kestrels fed intact chicks with a pellet of $P_4$ implanted in their crops, 8 died within 7 days. Of 15 kestrels fed chicks that had their upper digestive tracts removed to eliminate any pellets of white phosphorus, 3 also died. Haematocrit and haomoglobin in kestrels decreased, whereas lactate dehydrogenase-L, glucose, and alanine aminotransferase levels in plasma increased with exposure to contaminated chicks. Histological examination of liver and kidneys showed that the incidence and severity of lesions increased when kestrels were fed contaminated chicks. White phosphorus residues were measurable in 87% of the kestrels dying in the study and 20% of the survivors. This study shows that raptors can become intoxicated either by ingesting portions of digestive tracts containing white phosphorus pellets or by consuming tissues of $P_4$-contaminated prey.

**Sparling, D.W., M. Gustafson, P. Klein, and N. Karouna-Renier** (1997) Toxicity of white phosphorus to waterfowl: Acute exposure to mallards. *Journal of Wildlife Diseases*, **33**(2): 187–197.

As part of an effort to understand extensive, white phosphorus ($P_4$)-induced waterfowl mortality at Eagle River Flats, Fort Richardson, Alaska (USA), we conducted a number of acute toxicity tests using penned mallards (*Anas platyrhynchos*) in 1993 and 1994. The 24-hour median lethal dose ($LD_{50}$) for $P_4$ dissolved in oil was 6.46 mg/kg in adult males and 6.96 mg/kg in adult females. Although the median lethal doses were not statistically different, the female dose-response curve had a statistically shallower slope than that of males. The $LD_{50}$ for the ecologically more relevant pelletized form of $P_4$ in adult males was 4.05 mg/kg. In mallards, one mechanism of $P_4$ toxicity caused rapid (3 to 10 hour) mortality and had signs consistent with anoxia. A second, slower-acting mechanism resulted in hepatic and renal pathology, including extensive fat deposition in the liver and cellular necrosis. White phosphorus accumulated in adipose tissues, but only for a few days.

**Steele, B.B., L.R. Reitsma, C.H. Racine, S.L. Burson, R. Stuart, and R. Theberge** (1997) Different susceptibilities to white phosphorus poisoning among five species of ducks. *Environmental Toxicology and Chemistry*, **16**(11): 2275–2282.

Three species of ducks, mallard (*Anas platyrhynchos*), northern pintail (*Anas acuta*), and green-winged teal (*Anas crecca*), that frequent an estuarine salt marsh in Alaska during migration die in large numbers from ingesting particles of white phosphorus. Two other common species, northern shoveler (*Anas clypeata*) and American wigeon (*Anas americana*), are rarely found dead. Selectivity indices show that this difference in mortality is not ascribable to different numbers of each species being present. We investigated three hypotheses for the difference in susceptibility to this poison. First, we found that wigeons had more total grit in their gizzards than the susceptible species and shovelers had a high proportion of particles >1 mm compared to other species. Thus, ingestion of particles of white phosphorus as grit cannot explain the differences in susceptibility. Second, feeding behavior could not completely account for the lack of susceptibility in shovelers. Shovelers often forage with their neck or more in the water and often have their bills in the sediments. Wigeon, however, frequently forage with just their bill in the water and rarely penetrate the sediments. This feeding behavior, coupled with a diet consisting mainly of plants, may limit exposure of wigeon. Third, shovelers have wide upper bills, with lamellae consisting of long thin filaments extending from the upper bill inward toward the lower bill. These lamellae may allow white phosphorus particles to be flushed out during feeding. Thus, if physiological tolerance to white phosphorus is similar among these species, the difference in susceptibility appears to be attributable to differences in feeding behavior and bill morphology.

**Walsh, M.E.** (1995) Analytical method for white phosphorus in water. *Bulletin of Environmental Contamination and Toxicology*, **54**(3): 432–439.

An analytical method is described to determine white phosphorus ($P_4$) in water. The objective of this work was to develop an analytical method capable of meeting water quality criteria for the protection of aquatic organisms that uses standard analytical instrumentation. The development focused on a preconcentration step suitable for a volatile, air-sensitive chemical. An nonevaporative preconcentration step is used that takes advantage of the favorable partioning of $P_4$ between organic and aqueous phases ($K_{ow}$=1200) and the relatively high solubility of diethyl ether in water (6.9% w/w at 20°C). $P_4$ is extracted from water using diethyl ether (10:1 water:solvent ratio). The ether phase is collected, then reduced in volume shaking with reagent-grade water. By using the appropriate volume of water, excess is dissolved away, resulting in a preconcentration factor of 1000 while heat is avoided and loss of $P_4$ by volatilization minimized. $P_4$ is then determined by capillary gas chromatography and a nitrogen-phosphorus detector. (This abstract is an excerpt from the *Introduction*. This journal does not have an abstract section.)

**Walsh, M.E., C.M. Collins, and C.H. Racine** (1996) Persistence of white phosphorus ($P_4$) particles in salt marsh sediments. *Environmental Toxicology and Chemistry*, **15**(6): 846–855.

Remediation of sediments at Eagle River Flats, Alaska, a salt marsh contaminated with solid particles of white phosphorus ($P_4$), may require severe alterations of the wetland by dredging, draining, or covering. However, some sediments may undergo decontamination naturally in areas that are seasonally subaerially exposed. The persistence of millimeter-size $P_4$ particles was studied in laboratory and field experiments. White phosphorus particles were found to be persistent in saturated sediments. In unsaturated sediments, loss was rapid (within 24 hours) at 20°C, and was retarded by low temperatures.

**Walsh, M.E., and S. Taylor** (1993) Analytical method for white phosphorus residues in munitions-contaminated sediments. *Analytica Chimica Acta.*, **282**(1): 55–61.

An analytical method is described to determine white phosphorus ($P_4$) in sediments contaminated by smoke munitions. Experiments were performed to promote the extraction of $P_4$ from saturated sediment with a nonpolar solvent. $P_4$ extraction was enhanced by adding water to form a sediment-water slurry prior to shaking with isooctane for up to 24 hours. $P_4$ was determined with a portable capillary gas chromatograph equipped with a nitrogen-phosphorus detector. A certified reporting limit of 0.88 $\mu g\ kg^{-1}$ was estimated.

**Walsh, M.R., M.E. Walsh, and C.M. Collins** (1999) Remediation methods for white phosphorus contamination in a coastal salt marsh. *Environmental Conservation*, **26**(2): 112–124.

With the closure of many military bases worldwide and a closer scrutiny of practices on remaining bases, the environmental impact of the military is now an important consideration in the operation of bases. Many previously unknown environmental problems related to chemicals are surfacing. White phosphorus, commonly used as an obscurant, is a chemical previously thought to be innocuous after use. In 1990, however, it was linked to the deaths of thousands of waterfowl at the Eagle River Flats impact area on Ft. Richardson near Anchorage, Alaska, U.S.A., and shortly after, a series of remedial investigations was initiated. This paper describes three of the remedial methods currently under investigation, namely enhanced in-situ remediation, pond draining through ditching or pumping, or dredging. These three approaches are best applied in different environments, but they can be used together or in conjuntion with other strategies. Their impacts on the environment will vary as well.

Experience with these remediation strategies has proven very useful in determining the direction that the cleanup effort at Eagle River Flats (ERF) should take. Dredging, an effective means of removing contaminated sediments for off-site remediation, has been shown to be too slow and expensive at ERF because unexploded ordnance is present. Enhanced natural remediation is effective under favorable climatological conditions in areas that experience intermittent flooding, but desaturation of the sediments is critical to its effectiveness. Pond draining by blasting a ditch effectively removes waterfowl feeding habitat, but attenuation of the contaminant is inhibited because the ditch increases flooding frequency, and the habitat alteration is permanent. Pond pumping, where feasible, has shown great potential for the desaturating of wide areas of ERF, enabling the natural attenuation mechanism to progress. Further investigation will be necessary to confirm these initial conclusions and determine the overall effectiveness of all three methodologies. Methods developed over the course of this work may be applied to other remediation projects where in-situ volatilation can occur and limited disturbance of wetlands is critical.

## MAGAZINE ARTICLES

**Alaska** (1991) The jury's in. *Alaska*, **57**(8): 50.

**Alaska Geographic** (1991) Scientists solve mystery of duck deaths. *Alaska Geographic*, **18**(2 (supplement)): S11.

**Canterbury, C.** (1991) Military munitions blamed for waterfowl deaths at Eagle River. *Arctic Star*, **4**(8): 1.

**Clark, K.** (1991) Researchers unravel duck death mystery. *VOX of Dartmouth*, **IX**(28): 1.

**Darling, M.** (1999) U.S. Army, Army Corps, and DPW work together to save ducks. *Public Works*, **IX**(4): 10–11.

**Engineer Update** (1991) Solving the mystery. *Engineer Update*, **15**(6): 9.

**Public Affairs Office** (1991) White phosphorus linked as cause of waterfowl deaths at Alaskan firing range. *The Environmental Update*, **3**(2): 5.

**Walsh, M.R.** (1997) Dredging contaminated sediments at an active impact range: an ordnance avoidance success. *Ordnance and Explosives Environment*, **4**: 1.

## NEWSPAPER ARTICLES

**Alexander, D.** (1990) Scientists continue search for cause of wildfowl deaths. *Chugiak-Eagle River Star*, Eagle River, Alaska, 21 June.

**Alexander, D.** (1991) Phosphorus causes wildfowl deaths. Army starts environmental assessment. *Chugiak-Eagle River Star*, Eagle River, Alaska, 28 February, p. 1, 8.

**Anchorage Daily News** (1990) Bird deaths. Keep looking until answers appear. *Anchorage Daily News*, Anchorage, Alaska, 26 May, p. B10.

**Anchorage Daily News** (1990) Wildlife official requests Army abandon range. *Anchorage Daily News*, Anchorage, Alaska, 26 September, p. B1, B3.

**Anchorage Daily News** (1992) Army plans artillery practice. *Anchorage Daily News*, Anchorage, Alaska, 14 January, p. B2.

**Anchorage Daily News** (1992) Army to begin shelling Flats again. *Anchorage Daily News*, Anchorage, Alaska, 12 January, p. B2.

**Associated Press** (1991) Army fighting to save birds. *Anchorage Daily News*, Anchorage, Alaska, 30 September.

**Badger, T.A.** (1991) Wilderness magazine's request for photos irks Stevens. *The Anchorage Times*, Anchorage, Alaska, 1 June, p. B3.

**Balzar, J.** (1992) Mystery solved: The case of Anchorage's dying waterfowl. *Juneau Empire*, Juneau, Alaska, 23 March .

**Chugiak-Eagle River Star** (1991) Army pinpoints chemical hot spots. *Chugiak-Eagle River Star*, Eagle River, Alaska, 26 September, p. 7, 9.

**Chugiak-Eagle River Star** (1992) Army resumes firing into Eagle River Flats. *Chugiak-Eagle River Star*, Eagle River, Alaska, 9 January, p. 1.

**Fairbanks News-Miner** (1990) Duck deaths blamed on chemicals. *Fairbanks News-Miner*, Fairbanks, Alaska, 10 July, p. 5.

**Fairbanks News-Miner** (1992) Army opens fire on Eagle River Flats. *Fairbanks News-Miner*, Fairbanks, Alaska, 6 January, p. A5.

**McGee, R.** (1996) Deadly marsh keeps Army on its tiptoes. *Anchorage Daily News*, Anchorage, Alaska, 14 April, p. A1, A10, A11.

**Price, N.** (1990) Army checks soil for clues in bird deaths. *The Anchorage Times*, Anchorage, Alaska, 19 May, p. A1–A2.

**Price, N.** (1991) Phosphorus-tainted ducks pose low health risk on dinner table. *The Anchorage Time*, Anchorage, Alaska, 27 September, p. B5.

**Price, N.** (1992) Army plans to resume artillery exercises. *The Anchorage Times*, Anchorage, Alaska, 11 January, p. B1.

**Price, N.** (1992) Bombing on Eagle River Flats resumes. *The Anchorage Times*, Anchorage, Alaska, 4 January, p. B1, B6.

**Price, N.** (1992) Howitzers' effect on ice to be studied. *The Anchorage Times*, Anchorage, Alaska, 8 January, p. B1, B5.

**Rinehart, S.** (1990) Army tries to unlock secret of duck deaths. Explosives suspected, but similar mortality rate not found at other artillery ranges. *Anchorage Daily News*, Anchorage, Alaska, 19 May, p. B–1, B–3.

**Rinehart, S.** (1990) Report links Army shells to bird deaths. *Anchorage Daily News*, Anchorage, Alaska, 8 February, p. C1, C3.

**Rinehart, S.** (1991) Army links phosphorus, bird deaths. *Anchorage Daily News*, Anchorage, Alaska, 22 February, p. C1, C3.

**Saddler, D.** (1991) Smoke shells poison ducks. *The Anchorage Times*, Anchorage, Alaska, 22 February, p. B1, B3.

**Saddler, D.R.** (1990) Chemical suspected in duck deaths. *The Anchorage Times*, Anchorage, Alaska, 25 September, p. B1–B2.

**Shelton, W.** (1999) Engineers' Old Faithful: Charlie 84$^{th}$ soldiers make an impact in polluted Eagle River Flats using demolitions, courage. *Alaska Post*, Ft. Richardson, Alaska, **6**(24): 7.

**The Anchorage Times** (1992) Shots may be heard around town—if wind is right. *The Anchorage Times*, Anchorage, Alaska, 14 January, p. B2.

**Whitney, D.** (1990) Bird study prompts investigation. *Anchorage Daily News*, Anchorage, Alaska, 26 October, p. B2.

## PATENTS

**Clark, L., J. Mason, P. Shah, and R. Dolbeer** (1997) Method of identifying the avian repellent effects of a compound and methods of repelling birds from materials susceptible to consumption by birds. U.S. Patent 5,672,352.

There is provided by the invention a structure-activity model for identifying avian repellent compounds. It has now been found that certain topological and electronic features of a molecule, especially the presence of a core ring structure, the basicity of the molecule in general, and the electronegativity of the core ring structure, are predictive of its avian repellency. Such features may be used to identify avian repellent compounds and such compounds may be utilized in methods for repelling birds from consuming or utilizing a material. There are further provided by this invention novel avian repellents for use in methods of repelling birds from consuming or utilizing materials otherwise susceptible to consumption or utilization. Additionally, methods for repelling birds from consuming or utilizing non-potable aquatic habitats are provided herein.

**Henry, K.S.** (1997) Geosynthetic barrier to prevent wildlife access to contaminated sediments. U.S. Patent 5,601,906.

A geosynthetic barrier, adapted to deny wildlife access to contaminated sediments (CS), includes a geocomposite formed of a top layer juxtaposed on a bottom layer, which is adapted to be placed on the sediments. The top layer includes a geosynthetic drainage matrix having a plurality of openings formed so as to allow gasses to escape from the contaminated sediments on which said composite is placed. The openings in the bottom layer of the geosynthetic barrier have a size in the range up to 200 cm and are spaced apart on centers having a range of between 6 cm and 600 cm, for example. The geosynthetic drainage matrix may be a geonet, a geogrid or a geomesh, fabricated from polyethylene, polypropylene, high-density polypropylene, low-density polypropylene, polystyrene, or high-impact polystyrene. The top and bottom layers may be either separate layers, or may be joined together to produce a unified geocomposite web; may be held in place by a gravel layer or other means; may be used in a subaqueous or a non-subaqueous environment; and may provide a suitable environment through which vegetation can be rooted.

**Walsh, M.R., and D. Lambert** (1998) Debris exclusion device for an augerhead-type hydraulic dredge system. U.S. Patent 5,651,200.

The present invention pertains to debris exclusion devices designed for use on a small augerhead type hydraulic dredge system for operations in debris-laden channels that can cause the system's pump to malfunction. Debris to be excluded by these devices includes portions of trees, woody-stemmed plants, pieces of lumber, pieces of metal or even unexploded ordnance. A first embodiment comprises vertical grates with curved front surfaces mounted in front of a spoils inlet of a dredgehead shroud with cooperating cutter assembly attached to the auger. These grates are spaced to allow passage of spoils and small debris, but not larger injurious debris that is detrimental to the system's pump. A second embodiment is a tapered transition box device attached to the augerhead's shroud disposed between the grates of a spoils inlet leading through these grates and a hose feeding the system's pump. The box is a clean-out device, which is self-regulated and also maintains smooth transitional flow to the system's pump.

## REPORTS

**Clark, L., J.L. Cummings, S.A. Bird, J.E. Davis Jr., and P.A. Pochop** (1993) Preliminary evaluation of encapsulated methyl anthranilate at Eagle River Flats, Fort Richardson, Alaska. In U.S. Army Eagle River Flats: Protecting waterfowl from ingesting white phosphorus. USDA Denver Wildlife Research Center Technical Report 93–1, p. 34–57.

We evaluated methyl anthranilate encapsulated in a sodium alginate capsule at two field sites during the spring and at one site during the fall at Eagle River Flats, Fort Richardson, Alaska. Encapsulated formulations of MA were able to decrease feeding activity of ducks 50–80% for up to 10 days. Further, mallard mortality was reduced 60% when ducks were continuously exposed to WP contaminated areas for up to 172 days. Based on evaluation of several formulations and their performance in the field, recommendations are made for a final formulation that should have a half life of 10 days and an efficacy of at least 80% reduction of feeding activity. Sentinel studies should not be used to compare relative risk of MA vs control pens directly because even small sampling rates over a prolonged observation period place captive ducks at risk of WP poisoning. MA works by moving waterfowl away from areas of treatment, not by suppressing feeding 100%. Thus, field studies on free-ranging ducks are needed to further evaluate the efficacy of MA as a short-term remediation strategy.

**Collins, C.M., and D.J. Calkins** (1995) Winter test of artillery firing into Eagle River Flats, Fort Richardson, Alaska. USA Cold Regions Research and Engineering Laboratory, Special Report 95–2.

Winter tests of artillery firing were conducted in the Eagle River Flats impact range to determine the physical effects of exploding high-explosive (HE) projectiles on the ice-covered terrain. Eagle River Flats is an estuary at the mouth of the Eagle River used as the artillery impact range for Ft. Richardson. The Army suspended use of the impact range following the discovery that white phosphorus (WP) deposited in the salt marsh was responsible for large numbers of waterfowl deaths each summer. The purpose of these tests was to assess if seasonal firing of HE projectiles from 60- and 81-mm mortars and 105-mm howitzers into Eagle River Flats could be resumed without significantly disturbing the sediments contaminated with WP. The results of the test firings indicated that a minimum of 25 cm of ice over frozen sediment or a minimum of 30 cm of floating ice over shallow water was required to prevent disturbance of the WP-contaminated sediment by exploding 105-mm howitzer projectiles. Only 10 cm of ice was required to prevent disturbance by exploding 60- and 81-mm mortar projectiles.

**Cummings, J.L., L. Clark, S.A. Bird, J.E. Davis Jr., H.W. Krupa, and P.A. Pochop** (1993) Effects of methyl anthranilate bead formulations on mallard feeding behavior in an aqueous environment. In U.S. Army Eagle River Flats: Protecting waterfowl from ingesting white phosphorus. USDA Denver Wildlife Research Center Technical Report 93–1, p. 8–33.

We applied two methyl anthranilate (MA) bead formulation to bottom sediment in a simulated pond setting to evaluate bird repellency to captive mallards (*Anas platyrhynchos*). Formulations and application rates were: DP920324B (5% MA) applied at 5.4 kg/ha and SE920326 (5% MA) applied at 5.4, 10.8, and 21.7 kg/ha. The ineffectiveness of DP920324B to reduce mallard feeding in treated pools was attributed to the pliable structure of the beads. Mallards were unable to break the beads to release the methyl anthranilate. Experiments with SE920326 at application rates of 5.4 and 10.8 kg/ha showed slight treatment effects. SE920326 applied at 21.7 kg/ha to bottom sediment was effective in reducing the time mallards spent in treated pools ($p \leq 0.05$). SE920326 applied to contaminated waterfowl feeding areas at 21.7 kg/ha could reduce feeding and mortality and warrants further testing in the field.

**Henry, K.S., and S.T. Hunnewell** (1995) Silt fence testing for Eagle River Flats dredging. USA Cold Regions Research and Engineering Laboratory, Special Report 95–27.

An estimated 1000 to 2000 waterfowl deaths have been noted annually since 1980 in Eagle River Flats (ERF), Alaska, an artillery impact area used by the Army. Waterfowl die because of the ingestion of unburned white phosphorus (WP) particles deposited by incendiary rounds. Remediation of the site is currently being planned, and one of the techniques being considered is the use of a remote-control dredge to excavate WP-contaminated sediment. Dredged material will be placed into a settling pond and allowed to settle until a clear layer of water forms on the top of the sediments. The water will then be released over a weir, across a concrete pad, through a geotextile silt fence to a drain into the ERF. This report describes tests that were conducted to evaluate how well candidate geotextiles for the silt fence retained small particles (less than 0.1 mm in diameter) that were suspended in water being released back into the ERF. The soil used in the tests was collected from ponds to be dredged. The testing program consisted of two parts. Part I tests were standard engineering tests for silt fences, and were used to select a product for further testing. Part II tests simulated field conditions, and were conducted to determine whether the candidate geotextile selected was likely to perform well. Under simulated field conditions, the tests that used geotextiles achieved system filtering efficiencies of 99%, and the geotextile filter reduced the final total suspended solids contained in the water by a factor of 10. Negligible amounts of soil passed the no. 200 sieve from water that flowed through the geotextile. However, it is also noted that allowing the sediment to settle before decanting the water resulted in system filtering efficiencies in excess of

90% when a silt fence was not used in the test. Because of differences between lab and field use of this product, several recommendations are made to help ensure the proper functioning of the geotextile when used in Eagle River Flats. These recommendations include monitoring the quantity of material with diameters larger than 0.1 mm passing through the silt fence, careful and frequent visual inspection of the silt fence to detect any signs of strength loss or damage, having replacement geotextile available and properly stored at the site, backflushing the silt fence with water or rubbing it with a squeegee regularly to help ensure proper flow rates across it, and not allowing the depth of soil retained on the upstream side of the fence to exceed one-half of its height.

**Lawson, D.E., S.R. Bigl, J.H. Bodette, and P.B. Weyrick** (1995) Initial analyses of Eagle River Flats hydrology and sedimentology, Fort Richardson, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 95–5.

The physical environment of Eagle River Flats (ERF), a subarctic tidal flat and salt marsh, is progressively changing because of the interactions of multiple physical processes, including a high tidal range, two primary sediment sources, cold climate, and location within an active earthquake zone. In addition, ERF has been used by the U.S. Army as an artillery range, where high explosives or smoke-producing shells have been detonated, causing cratering and disrupting drainage. The physical environment of ERF needs to be understood to help remediate a problem of unusually high mortality rates in migrating waterfowl. This high mortality of ducks is attributable to ingestion of elemental white phosphorus ($P_4$) particles (from smoke-producing devices), which are now distributed within near-surface sediments of the ponds and marshes. The complexity of this dynamic environment makes it extremely difficult to predict what physical effects remedial measures for the $P_4$ contamination will have and, conversely, what short- and long-term effects the physical system will have on the effectiveness and success of proposed remedies. Understanding both the system's response and the effects of remedial technologies is critical to deciding what measures are used. This report presents the initial analysis of the physical processes of erosion, sedimentation, and sediment transport and the factors controlling their activity within a portion of ERF.

**Lawson, D.E., and B.E. Brockett** (1993) Preliminary assessment of sedimentation and erosion in Eagle River Flats, south-central Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 93–23.

The physical processes of sedimentation and erosion within the tidal mudflats and salt marshes of Eagle River Flats (ERF), an area used as an artillery impact range by the U.S. Army since 1945, must be understood to evaluate potential treatments of a high duck mortality resulting from ingestion of white phosphorus (WP) particles. The WP originates from smoke-producing devices detonated here. A preliminary assessment of erosion and sedimentation during May to September 1992 indicates that the physical system is complex and the intensity of these processes spatially variable. Deposition from suspension sedimentation generally varied with morphology and elevation, increasing inland from levees on the Eagle River (1 to 2 mm) across vegetated (3 to 6 mm) and unvegetated (5 to 12 mm) mudflats, and into ponds (10 to 19 mm) and salt marshes (10 mm). Resedimentation rates in ponds ranged from 8 to 16 mm. Recession rates of eroding gully headwalls were highly variable, ranging from negligible to over 3.9 m. White phosphorus particles may be in suspended transport through gullies during ebb. Further studies are necessary to better define annual sedimentation and erosion rates, with improved sampling techniques used at an expanded number of sites. Basic data on tidal inundation, sediment influx and efflux, and WP particle transport are required to develop appropriate treatment methods.

**Lawson, D.E., L.E. Hunter, and S.R. Bigl** (1996) Physical processes and natural attenuation alternatives for white phosphorus contamination, Eagle River Flats, Fort Richardson, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 96–13.

This report describes the results of investigations into the role of tidal flat physical systems in the natural attenuation of white phosphorus (WP) contamination in Eagle River Flats (ERF) on Fort Richardson, Alaska. Waterfowl feeding in ponds and marshes here ingest the WP and die. These investigations found that natural attenuation and in-situ degradation of the WP could result from certain physical phenomena operating within the ERF ecosystem. Specifically, the on-going erosion and headward recession in the gullies will drain large areas of contaminated ponds in an estimated 1 to 10 years. Lowering of water levels should lead to in-situ WP degradation and natural attenuation as pond sediments dry. Annual sedimentation rates in some ponds and marshes are sufficient to bury WP in several years or more and thereby reduce the exposure to feeding waterfowl. Ice and water are also effective transporters of WP, moving it about ERF and into Eagle River, and eventually into Knik Arm, where its fate is unknown. Certain areas of ERF will require artificial drainage, but natural conditions can be restored following treatment. Recommendations are made for the use of natural attenuation and additional studies that are required to ensure the successful cleanup of ERF.

**Lawson, D.E., L.E. Hunter, S.R. Bigl, B.M. Nadeau, P.B. Weyrick, and J.H. Bodette** (1996) Physical system dynamics and white phosphorus fate and transport, 1994, Eagle River Flats, Fort Richardson, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 96–9.

Eagle River Flats (ERF) is a subarctic estuarine salt marsh where human and natural forces are causing significant changes in the environment. Multiple internal and external forces govern the physical and chemical processes by actively altering surface conditions, sometimes in unpredictable ways. ERF is also used as an artillery range by the U.S. Army, where past use has resulted in white phosphorous (WP) contamination of the sediments within ponds and mudflats. Bottom-feeding waterfowl ingest this WP, which causes rapid death. This report documents analyses of the physical environment, describing the nature of the physical systems and factors controlling them. It includes data on sedimentation, erosion and hydrology. These investigations provide knowledge necessary to designing and evaluating remedial technologies. They also help determine the system's capacity to naturally attenuate the WP contamination.

**Racine, C.H., B.B. Steele, L. Reitsma, and C. Bouwkamp** (in press) Biodiversity inventory of Eagle River Flats, Upper Cook Inlet Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report.

An inventory of landcover-vegetation, flora, bird, and sediment macroinvertebrate faunas of Eagle River Flats (ERF), an 865-ha salt marsh on Upper Cook Inlet near Anchorage, Alaska, was conducted between 1991 and 1995. This work was carried out as part of an ecological risk assessment for white phosphorus contamination at ERF, used as a U.S. Army artillery training range for the past 40 years.

Landcover–landform classification and mapping was conducted using aerial photos for the entire salt marsh at two scales to show seven physiographic zones at a scale of 1:55,000 and more detailed waterbody and vegetation types at a scale of 1:27,000. Quantitative sampling of vegetation, avifauna, and macroinvertebrates included a daily population census of waterfowl, 425 1-$m^2$ plot samples of vegetation, and 82 macroinvertebrate sediment samples obtained in May, July, and August. Comprehensive species inventories as well as relative abundances and habitat relationships are presented here.

The flora of ERF includes over 65 species of vascular plants, including halophytic species characteristic of mud flat salt marsh, aquatic submerged, and emergent marsh species. The avifauna of ERF includes about 68 species of birds, including dabbling ducks, shorebirds, raptors, and granivores. Over 30 species of sediment macroinvertebrates were sampled from the bottoms of ponds and tidal creeks. The dipteran larvae *Chironomus salinarus* is the most common and abundant species particularly in shallow ponds with high salinites but less common in deeper ponds and tidal creeks.

Although small in area, ERF contains many of the same habitats and species found in other much larger estuarine salt marshes on Upper Cook Inlet but does not contain extensive tidal mudflats along the coastal edge, which likely affects the abundance of both waterbirds and invertebrates species.

**Racine, C.H., M.E. Walsh, C.M. Collins, D.J. Calkins, and B.D. Roebuck** (1992) Waterfowl mortality in Eagle River Flats, Alaska: The role of munition residues. USA Cold Regions Research and Engineering Laboratory, CRREL Report 92–5.

The deaths of hundreds of migrating dabbling ducks and 10–50 swans have been documented annually for the last 10 years in Eagle River Flats (ERF), an estuarine salt marsh on Ft. Richardson, Alaska. This marsh has been used for the past 40 years as an artillery impact range by the U.S. Army. During May and August 1990, CRREL collected 250 sediment and water samples and analyzed them for munitions residues. We found 2,4-DNT in a limited area of Eagle River Flats not used by waterfowl and white phosphorus in sediments from the bottom of shallow ponds where waterfowl feed. Tissues from waterfowl observed to die or found dead in the salt marsh were collected, and we found white phosphorus in the gizzards of all 11 carcasses collected in Eagle River Flats. Adult mallards dosed in the laboratory with white phosphorus showed identical behavioral symptoms to those of wild ducks observed to become sick and die in Eagle River Flats. All evidence indicates that white phosphorus, as a particulate in the sediments, is responsible for the death of waterfowl in Eagle River Flats. Since the bottom sediments of the shallow salt marsh ponds are anaerobic, the white phosphorus particles will persist in the sediments indefinitely and remain a threat to waterfowl.

**Racine, C.H., M.E. Walsh, C.M. Collins, S. Taylor, B.D. Roebuck, L. Reitsma, and B. Steele** (1993) White phosphorus contamination of salt marsh sediments at Eagle River Flats, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 93–17.

In 1990 we proved that an annual dieoff of thousands of waterfowl at Eagle River Flats (ERF), a 1000-ha estuarine salt marsh at Ft. Richardson, Alaska, was attributable to the ingestion of highly toxic particles of white phosphorus ($P_4$) that entered the bottom sediments of shallow ponds as a result of training with white-phosphorus smoke munitions. The anoxic conditions of the bottom sediments preserved the normally highly reactive white phosphorus. In 1991 we delineated the extent of white phosphorus contamination in the ponds of Eagle River Flats and further investigated the biological effects of WP contamination. Over 360 sediment samples were collected from six ponds where ducks were observed to feed and become sick and where carcasses of poisoned waterfowl were found. These ponds cover about 50 ha of the 1000-ha salt marsh. Sediment and tissue samples were analyzed for $P_4$ by gas chromatography. White phosphorus was found in 101 surface sediment samples and in sediment cores to depths of 20 cm. The distribution and highest concentrations of white phosphorus were localized in two of the six feeding pond areas, covering about 15 ha. We hypothesize that these two areas represent the major sources of waterfowl poisoning in ERF. While the locations in ERF where various species of waterfowl become sick showed close correlation with white phosphorus contamination in the sediments, dead waterfowl were also found in uncontaminated areas of ERF. No white phosphorus was found in over 300 gizzards of ducks harvested by hunters from various Cook Inlet marshes. Evidence for the transport of white phosphorus up the food chain from prey to predator was obtained in relation to the heavy feeding by bald eagles on $P_4$-containing duck carcasses and in the presence of white phosphorus in the tissues of one dead eagle found in ERF. We predict that white phosphorus will persist in ERF sediments and continue to poison waterbirds until remedial actions are implemented.

**Taylor, S., C.H. Racine, C.M. Collins, and E. Gordon** (1994) Ice formation in an estuarian salt marsh, Alaska. USA Cold Regions Research and Engineering Laboratory, Special Report 94–17.

An extensive ice sheet builds up during the winter in a salt marsh complex at the mouth of Eagle River near Anchorage, Alaska. To clarify how snow accumulation, periodic tidal flooding, and freshwater flow contribute to the ice cover, ice cores were taken along a transect beginning at a deep pond along the edge of the salt marsh and transversing marsh, shallow pond, and mudflat areas. Ice structure, ice salinity, ice thickness, and the presence or absence of sediment bands in the ice are described and were found to charge markedly along the transect.

**Taylor, S., and M.E. Walsh** (1992) Optimization of an analytical method for determining white phosphorus in contaminated sediments. USA Cold Regions Research and Engineering Laboratory, CRREL Report 92–21.

An analytical method was optimized to determine the concentration of white phosphorus (WP) in sediments contaminated by smoke munitions. The method uses isooctane as the extractant and a gas chromatograph as the determinative instrument. Both field-contaminated samples and spiked sediments were analyzed and results on the spiked samples indicate that the method has a better than 80% recovery rate for WP. The detection limit for the method is 0.88 µg/kg of soil. The WP recovery is sensitive to the water content of the sediments and to prolonged shaking. Fluidizing the wet sediments by adding water to saturated soil greatly increases WP recovery. Since field samples are contaminated with WP particles of various sizes, subsamples may not accurately represent the concentration of the sample as a whole.

**U.S. Army Environmental Hygiene Agency**

(1994) Water, sediment, macroinvertebrate, and fish sampling, Eagle River Flats, Fort Richardson, Alaska: 12–23 July 1993. U.S. Army Environmental Hygiene Agency, Final Report Receiving Water Biological Study No. 32–24-H1ZV–93.

The purpose of conducting this study was to assist Fort Richardson and CRREL by determining: 1) the concentration of possible contaminants in the water and sediments of the Eagle River Flats (ERF); 2) the concentration of possible contaminants migrating into the Eagle River from ERF; 3) the concentration of white phosphorus (WP) bioaccumulating in fish; 4) if WP or other contaminants were affecting the benthic macroinvertebrates in ERF.

In conclusion, of all chemicals analyzed, WP was the only one that could be attributed to the army's activities at ERF. There was only weak evidence of WP affecting the number of macroinvertebrates per unit area, and no evidence that it affected the species present or species diversity. No WP was detected in the stickleback fish living in the ponded areas of ERF.

In recommendation, the data collected in this study should be used to help complete the ecological and human health risk assessments.

**U.S. Army Environmental Hygiene Agency** (1995) Evaluation of white phosphorus effects on the aquatic ecosystem, Eagle River Flats, Fort Richardson, Alaska: 8–17 May, 22 August–9 September 1994. U.S. Army Environmental Hygiene Agency, Final Report Receiving Water Biological Study No. 32–24-H37Y–94.

The purpose for conducting these studies was two-fold: 1) to determine if white phosphorus (WP) concentrations at Eagle River Flats (ERF) are having an adverse impact on the aquatic biota or bioaccumulating in the aquatic food chain when the ducks and tidal movement have disturbed the sediments; 2) to determine a laboratory-derived no observable effect level (NOEL) concentration for WP in sediment.

In conclusion, the data from these studies indicate that a WP cleanup level would not be driven by effects on benthic macroinvertebrates or bioaccumulation in fish tissue. The benthic macroinvertebrate data indicate that WP is not affecting the diversity, number of species, or number of organisms per unit area in ERF. Out of 86 fish and invertebrate samples analyzed for WP from three studies, there were low levels detected in only three fish samples and one invertebrate sample in the fall 1994 study. One fish sample came from Area A and the rest were from Racine Island. The midge larva *Chironomus riparius* was the most sensitive species to WP in our sediment toxicity studies. The lowest $LC_{50}$ and the lowest NOEL were 256 and 26 µg/kg WP, respectively. There are concentrations above these levels in ERF, but our sampling of the benthic macroinvertebrates found no adverse effects on the community structure.

In recommendation, the data collected in this study should be used to help complete the ecological and human health risk assessments.

**United States Environmental Protection Agency** (1995) Method 7580: White phosphorus ($P_4$) by solvent extraction and gas chromatography. In Test methods for evaluating solid waste, physical/chemical methods (SW–846), Update III. Washington D.C.: U.S. EPA, Office of Solid Waste, p. 7580-1 to 7580-20.

Method 7580 may be used to determine the concentration of white phosphorus ($P_4$) (CAS Registry No. 7723–14-0) in soil, sediment, and water samples. This method includes two different extraction procedures for water samples. The first procedure provides sensitivity on the order of 0.01 µg/L, and may be used to assess compliance with Federal water quality criteria. The second procedure provides sensitivity on the order of 0.1 µg/L. The method includes one procedure for the extraction of soil/sediment samples which provides sensitivity on the order of 1 µg/kg. This method has been written as a stand-alone procedure, describing both the extraction and analytical techniques. White phosphorus is solvent extracted and analyzed in a gas chromatograph (GC) equipped with a nitrogen-phosphorus detector (NPD). (This abstract is a truncated version of the scope and application section of method 7580.)

**Walsh, M.E.** (1996) Method for producing performance evaluation soil/sediment samples for white phosphorus analysis. USA Cold Regions Research and Engineering Laboratory, Special Report 96–18.

The analysis of performance evaluation samples is a routine part of most quality assurance programs. However, performance evaluation samples are not commercially available for many contaminants. This report describes the development of performance evaluation samples for white phosphorus ($P_4$) analysis. To represent the wide range of concentrations that have been measured in field-contaminated sediment and soil samples, two types of performance evaluation samples were prepared. High concentration samples contained particulate white phosphorus in wet soil, and concentrations were stable for over 100 days. Low concentration soil samples containing white phosphorus dissolved in water or organic solvent were unstable. When silt-size glass beads were substituted for the soil, and a solution of white phosphorus in mineral oil added, concentrations were stable for over 2 months.

**Walsh, M.E., and C.M. Collins** (1993) Distribution of white phosphorus residues from the detonation of 81-mm mortar WP smoke rounds at an upland site. USA Cold Regions Research and Engineering Laboratory, Special Report 93–18.

Tests were conducted to determine the spatial distribution and short-term persistence of white phosphorus (WP) residue following the detonation of 81-mm mortar WP smoke rounds. At the point of impact, WP was driven into the soil matrix to a depth of 20 cm, resulting in a WP soil concentration on the order of 100 µg/g. Away from the point of detonation, the amount of WP residue deposited from the exploding shell decreased exponentially, with most of the WP found within a 10-m radius. The WP was deposited in the form of particles approximately 1 mm in length. Samples taken from craters four months after impact had WP concentrations around 20 µg/g, indicating that WP does not rapidly oxidize in a soil matrix.

**Walsh, M.E., C.M. Collins, R.N. Bailey, and C.L. Grant** (1997) Composite sampling of sediments contaminated with white phosphorus. USA Cold Regions Research and Engineering Laboratory, Special Report 97–30.

White phosphorus from exploded munitions is a difficult contaminant to characterize in the environment. Spatial heterogeneity of concentration estimates is extreme, varying over many orders of magnitude for closely spaced discrete samples. To provide cost-effective data upon which decisions may be made, two composite sampling methods were designed to aid in characterizing the site and monitoring the remedial process for an area contaminated by white phosphorus. For each method, closely spaced discrete samples were collected on a grid pattern and pooled to form composites. The composites were then divided by size fractions. Mean white phosphorus concentrations were estimated for the fine-grain-size fraction that was obtained by suspension with water. The presence of highly toxic solid white phosphorus particles, the form that may be ingested by feeding waterfowl, was determined in the coarse-grain-size fraction that was obtained by sieving.

**Walsh, M.E., C.M. Collins, and C.R. Racine** (1995) Factors that determine the persistence of white phosphorus particles in sediment. USA Cold Regions Research and Engineering Laboratory, CRREL Report 95–23.

Remediation of sediments at Eagle River Flats, a salt marsh contaminated with particles of white phosphorus ($P_4$), may require severe alterations of the wetland by dredging, draining, or covering. However, some sediments may undergo decontamination naturally in areas that are seasonally exposed to air. To predict the persistence of white phosphorus particles in sediments, a literature review was conducted for the physical and chemical properties of white phosphorus. The persistence of millimeter-size white phosphorus particles was studied by laboratory and field experiments. White phosphorus particles were found to be persistent indefinitely in saturated sediments. In unsaturated sediments, loss was rapid (within 24 hours) at 20°C and retarded by low temperatures.

**Walsh, M.E., and B. Nadeau** (1994) Preliminary evaluation of analytical holding times for white phosphorus in surface water. USA Cold Regions Research and Engineering Laboratory, Special Report 94–13.

A preliminary evaluation was made of the pre-extraction analytical holding time for white phosphorus in surface water samples. The purpose of the study was to determine the feasibility of shipping samples from a field site to a laboratory prior to extraction into an organic solvent. An initial screening study using spiked waters from four sources (reagent-grade water, well water, river water, and salt marsh water) showed that white phosphorus was stable in the two surface waters for approximately 1 week, provided precautions were taken to minimize losses to volatilization. Significant losses were observed in the reagent-grade water and the well water matrices. Following an ASTM standard, a holding time of 6 days was determined for surface water samples maintained at 4°C.

**Walsh, M.E., C.R. Racine, C.M. Collins, C. Bouwkamp, and P.G. Thorne** (1995) Simple field screening method for white phosphorus ($P_4$) in sediment. USA Cold Regions Research and Engineering Laboratory, Special Report 95–25.

A simple field screening method to detect white phosphorus particles in sediment is described. A thin layer of wet sediment is heated until all water evaporates. The presence of white phosphorus is indicated by visual detection of the inflammation of white phosphorus particles that occurs at relatively low temperatures (less than 40°C) once a protective layer of water is removed. The field screening method consistently gave positive results for samples where solvent extraction followed by gas chromatography indicated white phosphorus concentrations above 1 µg/g. A more sophisticated method, based on solid-phase microextraction and gas chromatography determination, was also tested. Concentrations less than 1 µg/kg were detectable.

**Walsh, M.E., S. Taylor, and P.G. Thorne** (1996) Development of an analytical method for white phosphorus ($P_4$) in water and sediment using solid-phase microextraction. USA Cold Regions Research and Engineering Laboratory, Special Report 96–16.

Headspace solid-phase microextraction (SPME) methods were developed for white phosphorus in water and sediment/soil to minimize waste generated by methods based on solvent extraction. Headspace SPME provided a rapid, nonexhaustive extraction, based on equilibrium, of white phosphorus. Comparison of results obtained by headspace SPME and solvent extraction shows that headspace SPME may be used quantitatively for some water matrices and qualitatively for more complex matrices such as sediment/soil. Because detection limits appear to be similar to those obtained by solvent extraction, headspace SPME can be used to rapidly screen samples for contamination, eliminating the need to solvent-extract most samples.

**Walsh, M.R., E.J. Chamberlain, K.S. Henry, D.E. Garfield, and E. Sorenson** (1996) Dredging in an active artillery impact area, Eagle River Flats, Alaska. USA Cold Regions Research and Engineering Laboratory, Special Report 96–22.

Remediation of sediments in permanently ponded areas at Eagle River Flats, a salt marsh contaminated with white phosphorus (WP), may require dredging. Because the Flats were used as a firing range impact area for over 40 years by the U.S. military, there is much unexploded ordnance, which will require that any dredging equipment be remotely controlled. To treat the sediment pumped from dredged areas, a spoils retention basin was designed, constructed, and tested. This basin contains several innovations, including a natural peaty-silt liner and a geofabric barrier to inhibit reintroduction of WP into the environment, and is designed for the natural remediation of the WP. The dredging system was deployed in October of 1994, with sampling indicating that WP-contaminated areas were removed from the dredged area. An early snowfall curtailed operations shortly after initiation.

**Walsh, M.R., and C.M. Collins** (1998) Dredging as remediation for white phosphorus contamination at Eagle River Flats, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Report 98–5.

The Eagle River Flats impact area is a Ft. Richardson Superfund site. It is a salt marsh that is contaminated with white phosphorus (WP), and remediation of sediments in permanently ponded areas may require dredging. A remotely piloted dredging system was designed, constructed, and deployed at the Flats as part of the overall site remediation feasibility study. Experience gained over 2 years of engineering study and contract operation indicates that, although feasible and effective, this alternative is slow, difficult, and very expensive.

---

## THESES

**Hansen, T.A.** (1995) The persistence of white phosphorus in unsaturated sediments. Master of Science, Dartmouth College.

Particulate white phosphorus ($P_4$) contamination is the cause of catastrophic waterfowl dieoffs at Eagle River Flats, Alaska. As this is the first documented case of $P_4$ persistence in sediments, little knowledge regarding processes affecting persistence is available. Knowledge of the behavior of particulate $P_4$ in unsaturated sediments is valuable in the development of remediation plans and estimations of persistence of $P_4$ in sediments.

To gain insight into $P_4$ persistence, particulate $P_4$ persistence in unsaturated sediments was modeled. Modeled processes include the sublimation of solid $P_4$ to vapor, the diffusion and chemical reaction of $P_4$ vapor and oxygen, the production and buildup of the reaction product, $P_4O_{10}$, in the soil, altering the local soil porosity, and various temperature dependencies of the physical and chemical parameters involved. Soil characteristics for Eagle River Flats sediments were also determined for inclusion in the model.

Buildup of $P_4O_{10}$ coincides with an experimentally observed ring of discolored sediment surrounding the initial location of $P_4$ particles after air drying of sediments. But, the buildup of these products in the soil is found to have no effect on the persistence process for small particles. Oxygen depletion in the soils is also found to be negligible.

Model simulations of particulate $P_4$ persistence are also insensitive to the Kelvin effect of particle curvature on vapor pressure. Further, the consumption of $P_4$ and oxygen by the chemical reaction only affects predicted persistence times slightly. However, the persistence of $P_4$ depends largely upon the sediment and particle temperature, which mainly affects the vapor pressure, and the sediment air filled porosity.

When compared to previous laboratory experimental studies on $P_4$ persistence at low temperatures and high air-filled porosities, the model results show good agreement. At low air-filled porosities, a nonlinear correlation for the calculation of effective diffusion coefficients in sediments is found to be more appropriate than the linear Penman relationship. Also, at higher temperatures, the autocatalytic effect of the highly exothermic reaction of $P_4$ vapor and $0_2$ and resulting temperature increases may explain the large deviations from experimental data. Inaccuracies in the estimation of effective diffusivities may also affect model simulations.

Implications of model results for site remediation are discussed. The level of natural attenuation of $P_4$, verified by field data, is predicted by the model within reason. Conditions required for assisted attenuation of saturated sediments are calculated for average summer site conditions. It is estimated that, when appropriately drained, sediments at Eagle River Flats may be decontaminated during a single summer.

Future work is needed to obtain an accurate estimate of the effective diffusion coefficient of $P_4$ in sediments of interest. Also, the effect of the heat generated by the exothermic reaction must be investigated further and included in the model. Soil water content gradients and evaporative processes, as well as oxygen concentration gradients within the soil, are also identified as potentially important factors to be included in future modeling efforts.

**Nam, S.I.** (1995) The environmental impact of white phosphorus on avian species. Doctor of Philosophy, Dartmouth College.

White phosphorus ($P_4$) has been implicated in thousands of waterfowl deaths at Eagle River Flats (ERF), an estuarine salt marsh located near Anchorage, Alaska. $P_4$, a well-known toxicant, is lethal to a wide range of species. The toxic effects of $P_4$ have been reported in humans, numerous aquatic species, livestock, and laboratory animals. However, $P_4$ toxicity in avian species is not well characterized, and the basic mechanisms of $P_4$ toxicity are still not understood. The primary objective of this thesis was to better understand and characterize $P_4$ toxicity in avian species.

Mallards dosed with a lethal quantity of $P_4$ exhibited behaviors characteristic of $P_4$ poisoning at ERF and died within 4 hours of exposure. $P_4$ tended to distribute mostly into the fatty tissues.

In an experiment designed to simulate predation events at ERF involving $P_4$-poisoned ducks, $P_4$ was found not to accumulate in tissues of kestrels. When $P_4$ in the diet was decreased, depuration of $P_4$ was observed.

In chickens dosed with $P_4$, rapid absorption into tissues was observed. $P_4$ was also detected in the eggs of chickens dosed with sublethal doses of $P_4$. Laying frequency was reduced in chickens receiving sublethal doses for 5 days.

Studies were undertaken to determine if $P_4$ toxicity varied with the form of $P_4$ administered and to assess whether ducks could be therapeutically treated for $P_4$ poisoning. No significant variance in survival time was observed between groups with either dissolved or particulate $P_4$. Short latent periods between first signs of intoxication and subsequent convulsion argued against effective treatment.

In vitro studies demonstrated that phosphine ($PH_3$), a toxic gas, is generated from $P_4$ by various rat tissues. Viable samples of blood and brain produced significantly more phosphine that did heat-denatured samples, suggesting enzymatic mediation.

In toto, these data suggest that $P_4$ is readily absorbed from the digestive tract and that death follows 4 to 5 hours after exposure. Toxicity may be ascribable more to the metabolite phosphine than to $P_4$ itself. The potential for accumulation up the foodchain appears limited, but the mobility of $P_4$ into eggs raises concerns about possible reproductive effects and broader ecosystem impacts.

**Walsh, M.E.** (1993) White phosphorus: An environmental contaminant. Master of Science, Dartmouth College.

White phosphorus ($P_4$) is the toxic agent in a catastrophic waterfowl dieoff at Eagle River Flats, a salt marsh on Cook Inlet, Alaska. The marsh was used by the U.S. Army as an impact area for artillery training. Training with smoke-producing munitions containing $P_4$ resulted in contamination of the sediments of shallow ponds where waterfowl feed. Eagle River Flats is the first Army training area identified with $P_4$ contamination.

To characterize the contamination and to evaluate remediation strategies, analytical methodology was developed to measure $P_4$ concentration in saturated sediments. The $P_4$ was found to be in the form of particles that are similar in size to seeds, invertebrates, and grit ingested by waterfowl.

$P_4$ particles are persistent in the saturated sediments of Eagle River Flats. To determine ways to decontaminate the sediments, the physical and chemical properties of $P_4$ were reviewed. Laboratory studies, involving the air-drying of contaminated sediments, showed that loss of moisture was accompanied by loss of $P_4$ once the moisture content was reduced to less than 20%. After 2 weeks of air-drying, $P_4$ loss was 99%.

The loss of $P_4$ was modeled. Factors that determine the persistence of particles are hypothesized to be sediment porosity, moisture, and temperature, which interact to determine the rate at which the $P_4$ particles sublime to form $P_4$ vapor. Previous models and studies of $P_4$ persistence in soil have focused on the availability of oxygen. Oxidation of $P_4$ is a vapor phase reaction. While oxygen is important in the detoxification of $P_4$, the principal mechanism determining the persistence of $P_4$ particles is hypothesized to be the rate at which $P_4$ sublimes. Oxygen may slow sublimation by the formation of oxidation products around the $P_4$ particles that impose a diffusion barrier to $P_4$ vapor.

## VIDEO TAPES

**L'Heureux, D.A., M.R. Walsh, and D.R. Boden** (1998) Cooperative military operations in support of remediation efforts: Eagle River Flats, Alaska. USA Cold Regions Research and Engineering Laboratory, CRREL Video Tape #T98013.

**Collins, C.M., L. Angell, and D.A L'Heureux** (1996) Cooperative blasting operation: Eagle River Flats Racine Island Pond drainage. USA Cold Regions Research and Engineering Laboratory, CRREL Video Tape #T96021.

**Walsh, M.R., and D.A L'Heureux** (1996) ERF dredging remediation pilot project. USA Cold Regions Research and Engineering Laboratory, CRREL Video Tape #T96003.

**Gossweiler, W.A., and D.A. L'Heureux** (1995) Eagle River Flats: An Army environmental rescue operation. USA Cold Regions Research and Engineering Laboratory, CRREL Video Tape #T95003.

**Walsh, M.R., and D.A. L'Heureux** (1995) Eagle River Flats dredge control cab blast tests. USA Cold Regions Research and Engineering Laboratory, CRREL Video Tape #T95002.

## WEB SITES

**Mason, J., S.I. Nam, and M.R. Walsh** (1998) Eagle River Flats Web Site (http://www.crrel.usace.mil)

This site contains information on and links to material related to the Eagle River Flats, Alaska, remedial project. Included are images of the various projects conducted at the Flats, maps, aerial photographs, and the ERF bibliography. The site is currently under development and will be accessible through the CRREL home page in the near future.

**McLane, M., and M.R. Walsh** (1998) Eagle River Flats meteorological and test site data.

This site displays near-real-time data from the CRREL Met Station located at Eagle River Flats, as well as data from test site instrumentation located in ponds undergoing treatment. Meteorological data are displayed in tabular format for the previous day, and in graphical format for the previous day, as well as for the season to date. Data include precipitation, radiance, air temperature, evaporation, and wind speed. Test site data are displayed in graphical format for each of the sites. Data include average and maximum soil temperatures, average and maximum soil moisture, soil tension, and average water depth. This web site is evolving as work progresses and needs arise. It is found on the Eagle River Flats web site.

## LATE SUBMISSION

**ESE** (1990) Eagle River Flats expanded site investigation. Ft. Richardson, Alaska. Environmental Science and Engineering, Inc. Final Technical Report. Prepared for the U.S. Army Toxic and Hazardous Materials Agency, Aberdeen Proving Ground, Maryland. Data Item A011.

The Eagle River Flats (ERF) Expanded Site Investigation was conducted in order to evaluate the potential causes of waterfowl mortality at ERF. Related objectives were to determine potentially relevant site and contaminant characteristics. The conceptual approach was to conduct a controlled, well-documented, and phased investigation of ERF in order to determine both the cause and probable sources of bird mortality. The study was designed to test all probable hypotheses concerning the causes of mortality. This study built upon previous investigations of the problem by Fort Richardson environmental personnel and other agencies included in the Eagle River Task Force. Specific methods included necropsy, hematology, histopathology, and bacterial culture studies of affected waterfowl; integrated sampling of sediment, water and waterfowl tissue for contaminants; and bioassays (laboratory and in situ).

The Technical Plan was developed with input from and review by the Eagle River Task Force. The plan was modified twice during the field season on the basis of results obtained during the early phases of the study. Laboratory bioassay studies conducted in June 1989 indicated that water and possibly sediment from some locations on ERF at certain times were responsible for bird mortality, and indicated that the causative substance was not transferred through plants in the food chain. Sentinel bird (in situ bioassay) studies were subsequently conducted in ERF, which produced similar results. Bioassay studies also permitted close observation and documentation of the sequence of symptoms leading to morbidity in waterfowl.

Clinical studies (e.g., histopathology, etc.) eliminated infections disease, concussion, and inhalation of toxic substances as causes of waterfowl mortality. Laboratory testing also indicated that algal toxins were probably not the cause of the bird mortality at ERF. Field observations provided information on the seasonal distribution of wild birds. Results indicated that waterfowl, particularly dabbling ducks, were the group primarily affected and that the causative substance apparently did not produce secondary effects in predators or scavengers (e.g., bald eagles, gulls, etc.) that fed on affected waterfowl.

Integrated sampling of contaminants found a statistically significant relationship ($p < 0.05$) between explosives related contamination and affected ducks, indicating that chemicals from explosive ordnance were a probable cause of waterfowl mortality on ERF. Specific chemicals were not identified. Nitrates / nitrites and phosphorus in sediments correlated significantly ($p < 0.1$) with adverse effects in sentinel birds. Information from Army records indicates that destruction of large quantities of magnesium flares within ERF was a likely cause of observed elevated levels of magnesium in Area C. Analysis of explosives chemicals in duck tissues was not achieved owing to difficulties in extraction procedures. Results from sentinel bird studies indicated that the temperature may inversely affect the presence or persistence of the chemicals in ERF (temperature correlated inversely with adverse effects in sentinel birds, $p < 0.1$).

## INDEX TO ABSTRACTS

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. AGENCY USE ONLY (Leave blank) | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | xxxxxx 1999 | |

4. TITLE AND SUBTITLE

Eagle River Flats Remediation Project:
Comprehensive Bibliography—1950 to 1998

5. FUNDING NUMBERS

6. AUTHORS

Sae Im Nam, Michael R. Walsh, Charles Collins, and Lisa Thomas

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER

Special Report 99-xx

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Environmental Center
Abderdeen Proving Ground, Maryland

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES For conversion of SI units to non-SI units of measurement consult *Standard Practice for Use of the International System of Units (SI),* ASTM Standard E380-93, published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pa. 19428-2959.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

White phosphorus (WP) has been implicated in the deaths of thousands of waterfowl annually at Eagle River Flats (ERF), an estuarine salt marsh located on Fort Richardson near Anchorage, Alaska. The source of WP contamination at ERF was the firing of WP-containing munitions into the area by the U.S. military. WP is a well-known toxicant and is lethal to a wide range of species. However, WP contamination at ERF is the first documented case of a U.S. Army munitions impact area contaminated with WP particles. This has led to the designation of ERF as a Superfund site by the U.S. Environmental Protection Agency, and the Army must follow the guidelines of remediation set by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Numerous studies have been conducted to better characterize the nature and the extent of WP contamination, and treatability studies for remediation processes are currently being implemented. This comprehensive bibliography provides all publications related to WP contamination remediation project at Eagle River Flats through 1998.

14. SUBJECT TERMS

| | | |
|---|---|---|
| Abstracts | Eagle River Flats | Superfund |
| Bibliography | White Phosphorus | Wetlands |
| Contamination | Remediation | |

15. NUMBER OF PAGES 103

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

to contents

to index